New Horizon of Particle Physics Explored by Higgs Physics

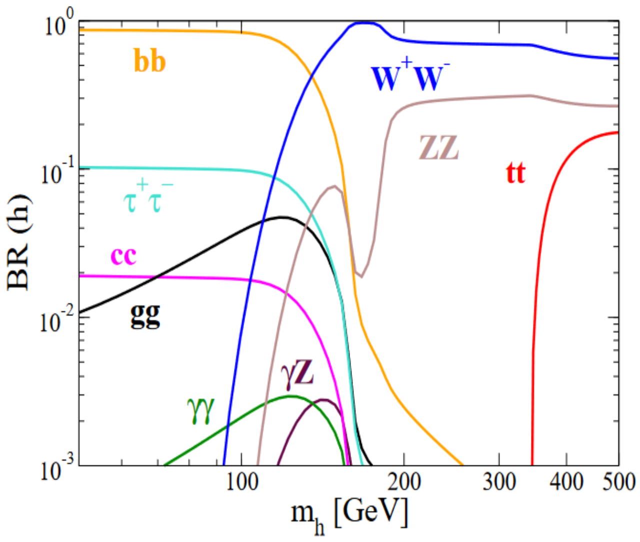
Kei Yagyu（Osaka U. ）

2021, 14th Dec., U. of Toyama

Toyama Station: Before → After

Particle Physics: Before → After

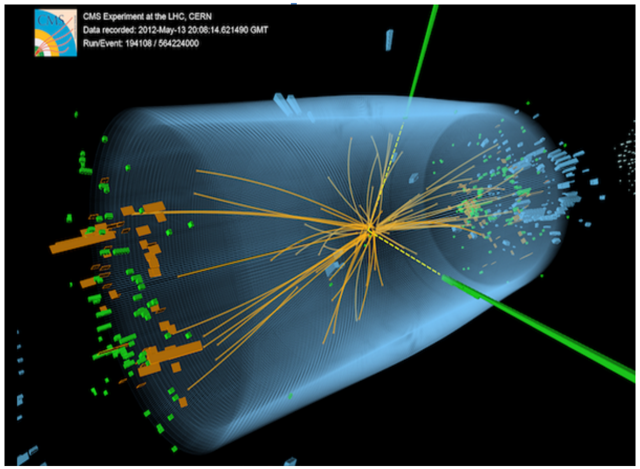
It was a hypothetical particle.

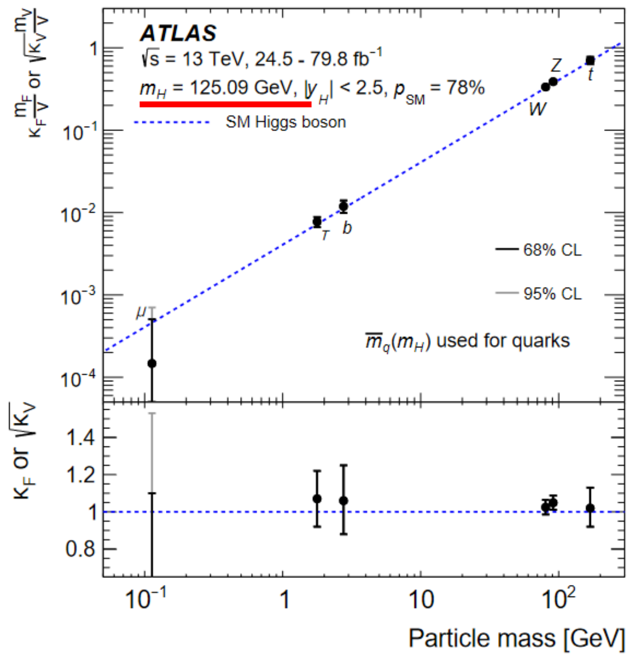


KY, PhD thesis (2012)

It was discovered, measured precisely.

2012, July

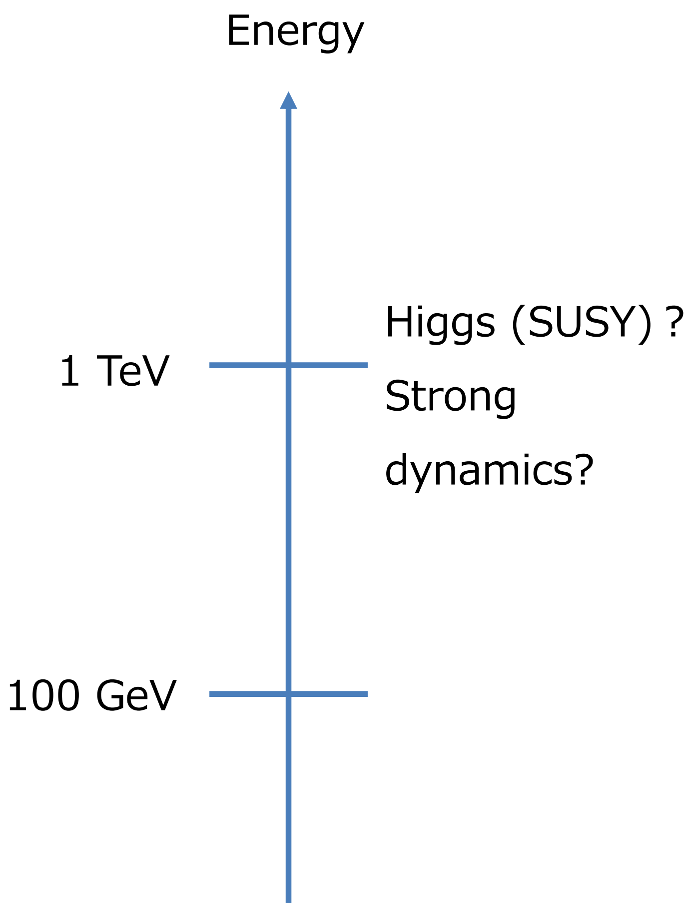




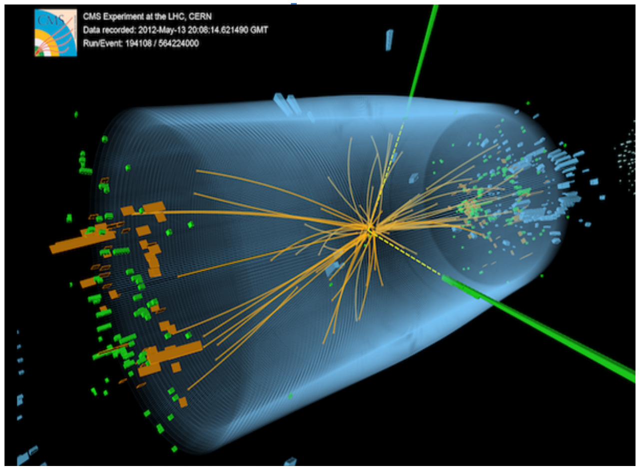
Particle Physics: Before → After

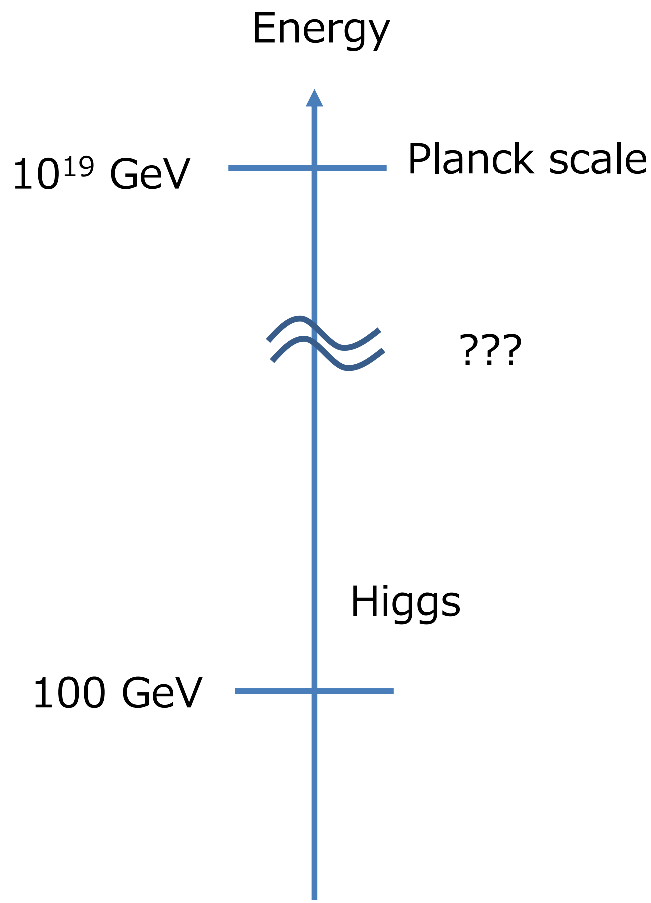
There was a no-loose theorem.

Previous concepts are broken, and now is a kind of Sengoku-era.



2012, July





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I. What is the Higgs boson?

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III. How can we determine the Higgs sector?

- Bottom-up approach
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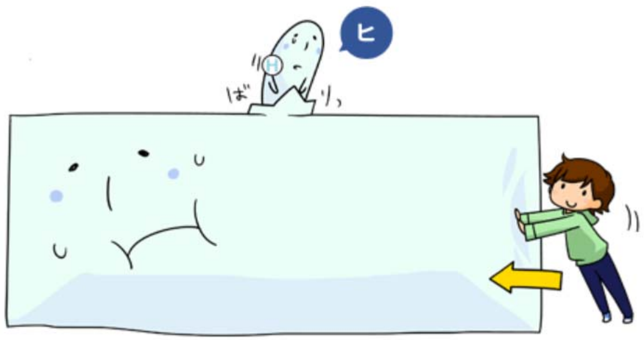
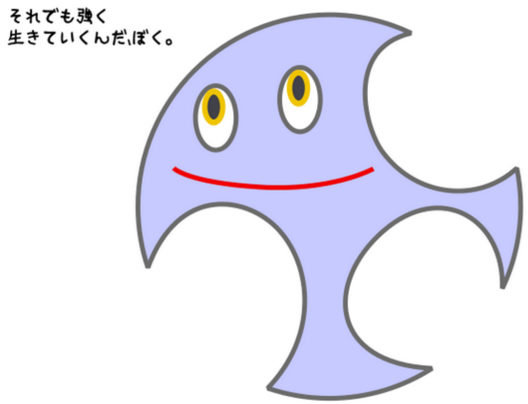
The Higgs boson

"Higgs-Tan"



"Higgs-Kun"



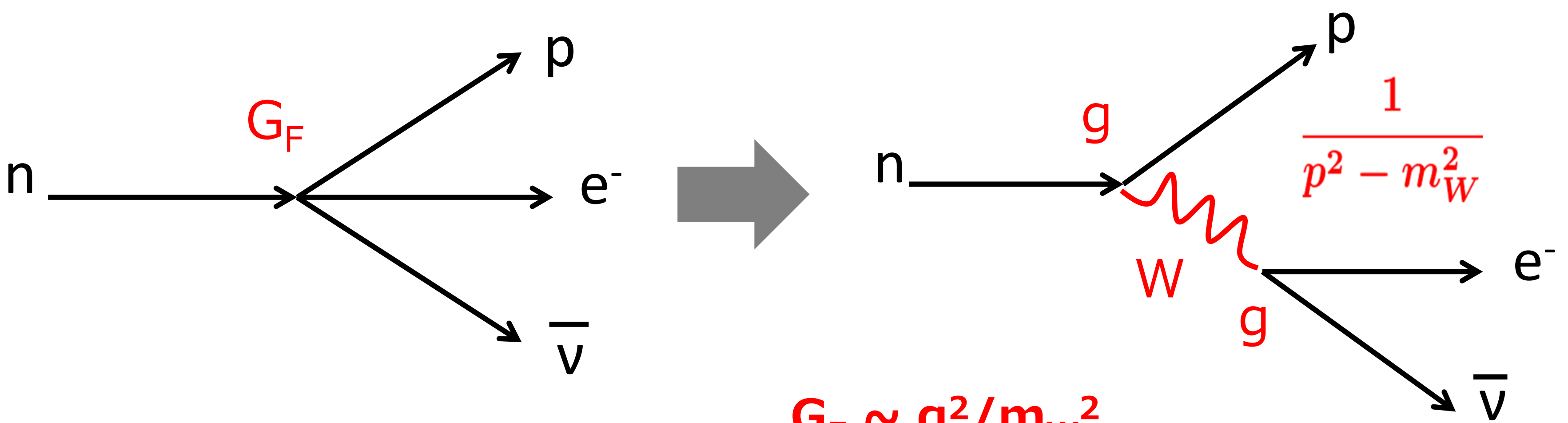
"Higgs-Doll"

Weak force

E. Fermi

1933: Fermi's theory for beta decays

G_F : Fermi const. ~ 10^{-5} GeV^{-2}

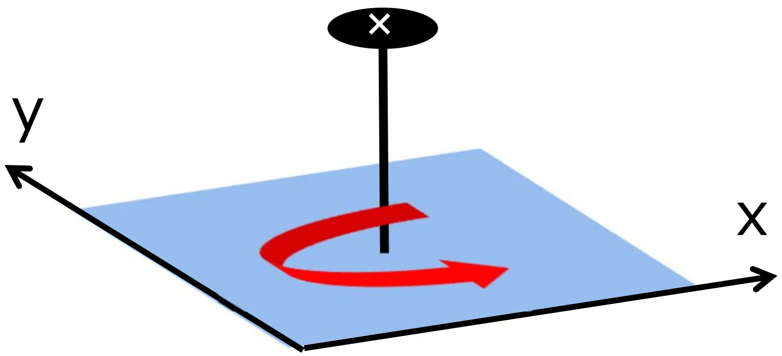


$G_F \sim g^2/m_W^2$

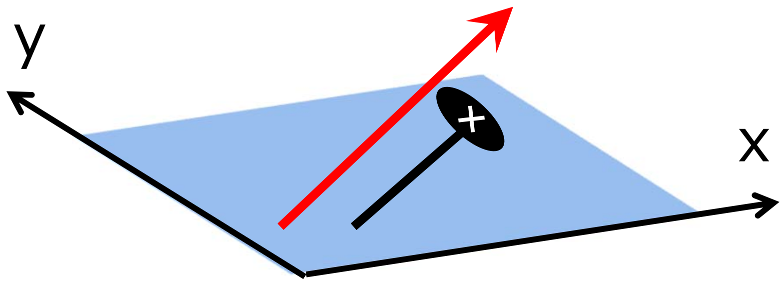
m_W = O(100) GeV

Gauge boson masses are forbidden by the gauge principle.

Spontaneous symmetry breaking



Unstable, but symmetric under rotation



Stable, but not symmetric under rotation

Y. Nambu

Gauge boson masses are generated by spontaneous symmetry breaking.

Scalar QED (Higgs model)

P. Higgs R. Brout F. Englert

Particles : Comp. scalar $\Phi(x)$, gauge field $A_\mu(x)$

Symmetry : Local U(1)

$$\phi \to e^{i\alpha(x)}\phi$$

$$A_\mu \to A_\mu + \frac{1}{e}\partial_\mu \alpha(x)$$

Lagrangian :

$$\mathcal{L} = (D^\mu \phi)^*(D_\mu \phi) - V(|\phi|^2) - \frac{1}{4}F^{\mu\nu}F_{\mu\nu}$$

$$D_\mu \phi = (\partial_\mu - ieA_\mu)\phi \qquad F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu$$

$$m_A^2 A_\mu A^\mu \to m_A^2 (A_\mu + \partial_\mu \alpha / e)(A^\mu + \partial^\mu \alpha / e)$$

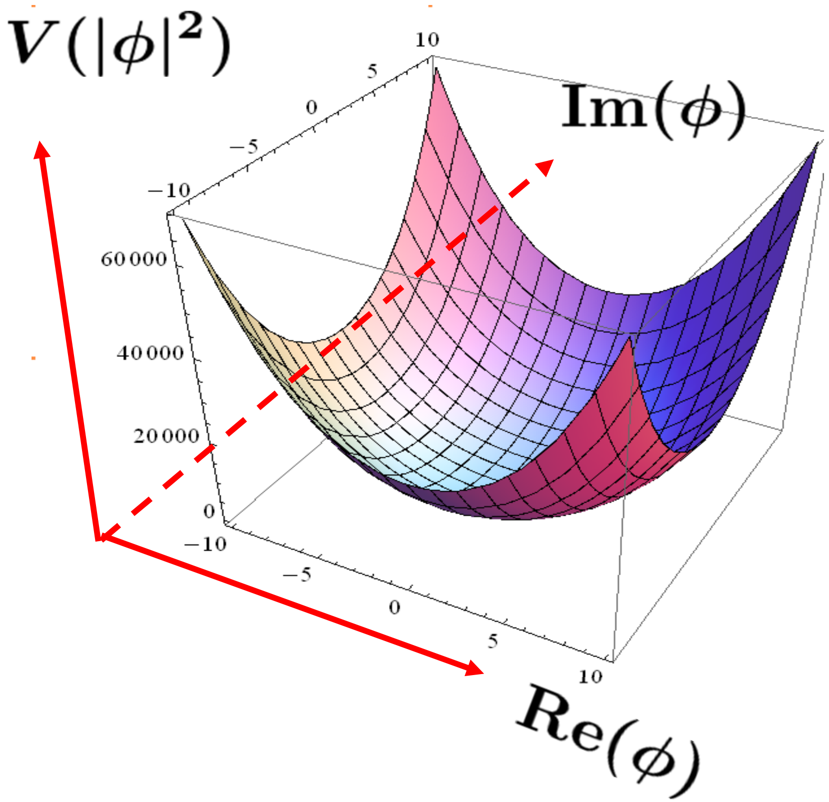
Potential :

$$V = \mu^2|\phi|^2 + \lambda|\phi|^4$$

Scalar QED (Higgs model)

$$V = \mu^2|\phi|^2 + \lambda|\phi|^4$$

$\mu^2 > 0$



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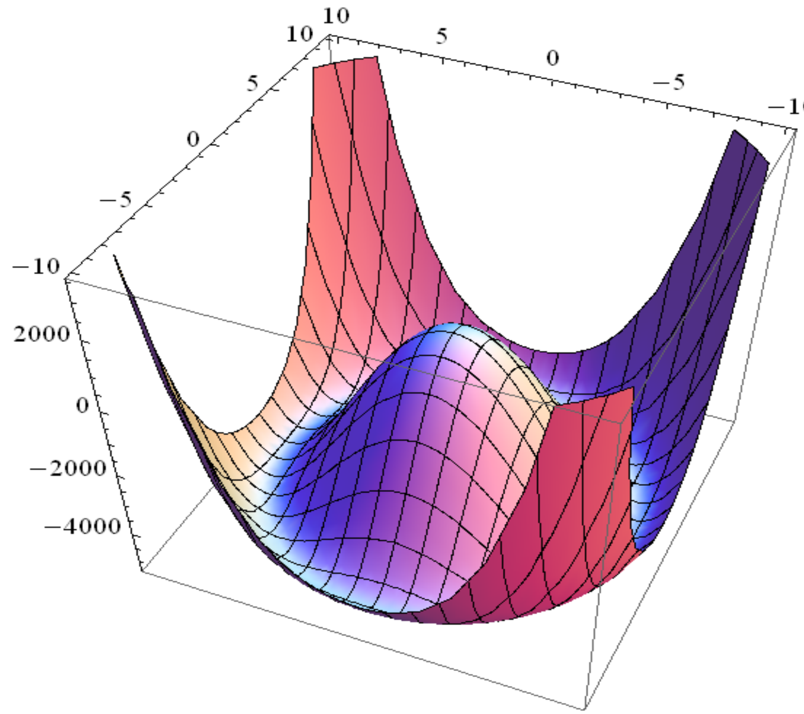
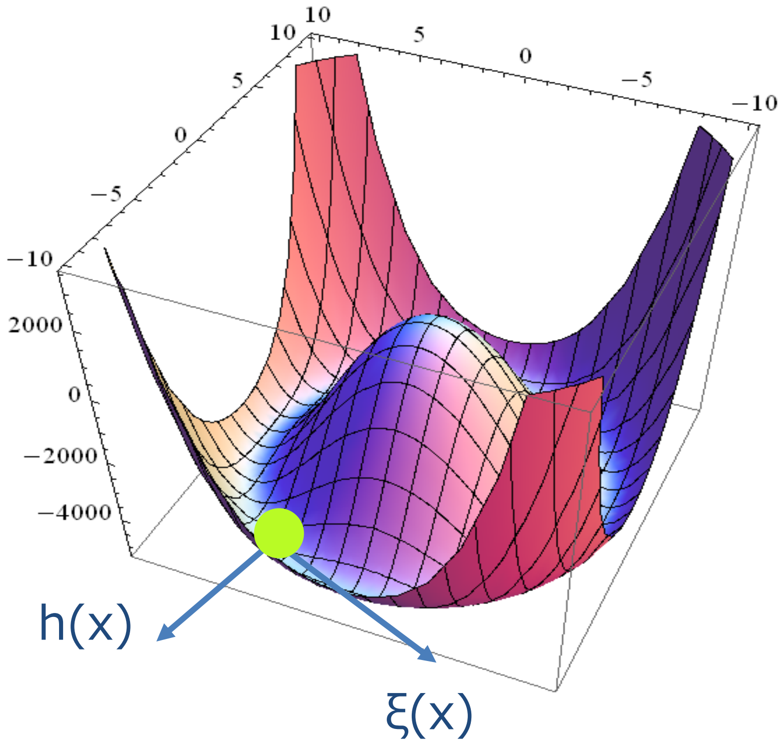


Scalar QED (Higgs model)

- Field expansion at around the minimum :

$$\phi(x) = [h(x) + v]e^{i\xi(x)/v}$$

Nambu-Goldstone boson (NGB)



$$\phi \to e^{i\alpha(x)}\phi$$
$$A_\mu \to A_\mu + \frac{1}{e}\partial_\mu \alpha(x)$$

$$\phi \to e^{-\frac{i\xi(x)}{v}}\phi$$
$$A^\mu \to A^\mu - \frac{1}{ev}\partial^\mu \xi(x)$$

$$D_\mu \phi = (\partial_\mu - ieA_\mu)\phi$$

Gauge boson mass

$$(D_\mu \phi)^*(D^\mu \phi) \to (ev)^2 A_\mu A^\mu + \cdots$$

NGB is “eaten” by the longitudinal comp. of the gauge boson, and h (= Higgs particle) remains as a physical d.o.f.

Scalar QED (Higgs model)

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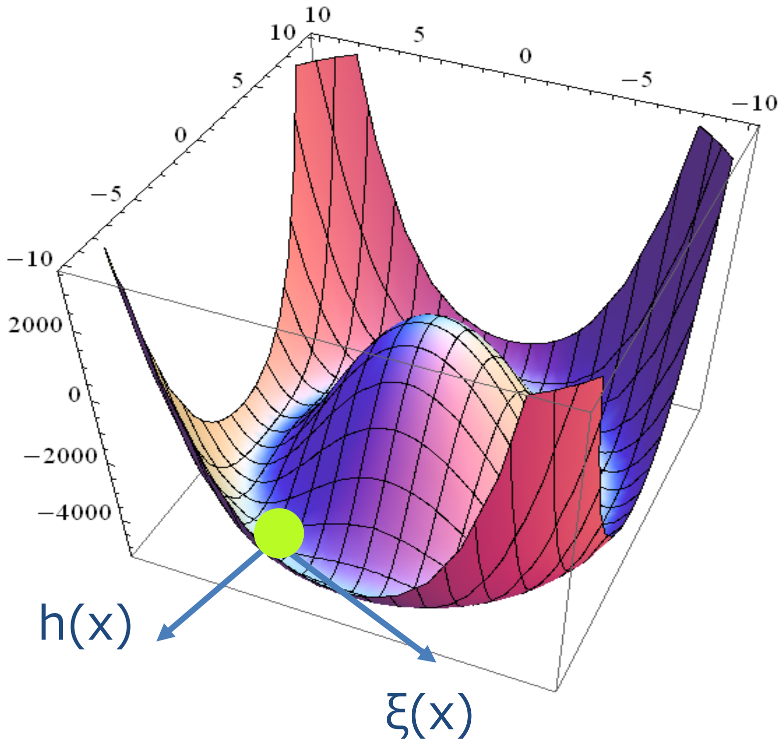

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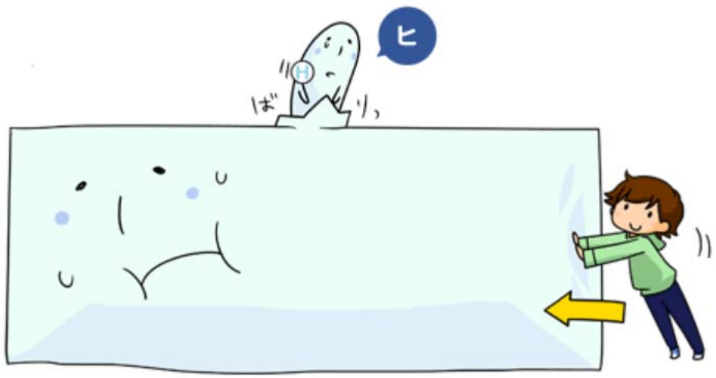
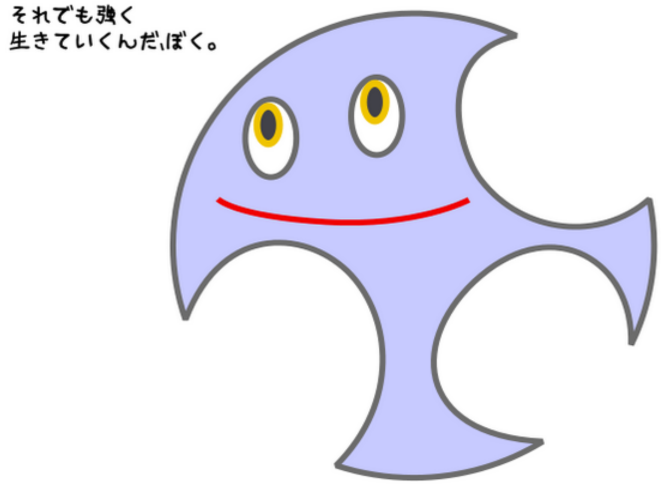


Spontaneous EWSB

Higgs field Φ(x): SU(2) doublet $\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix}$, Gauge fields (W^+,W^0,W^-), B^0

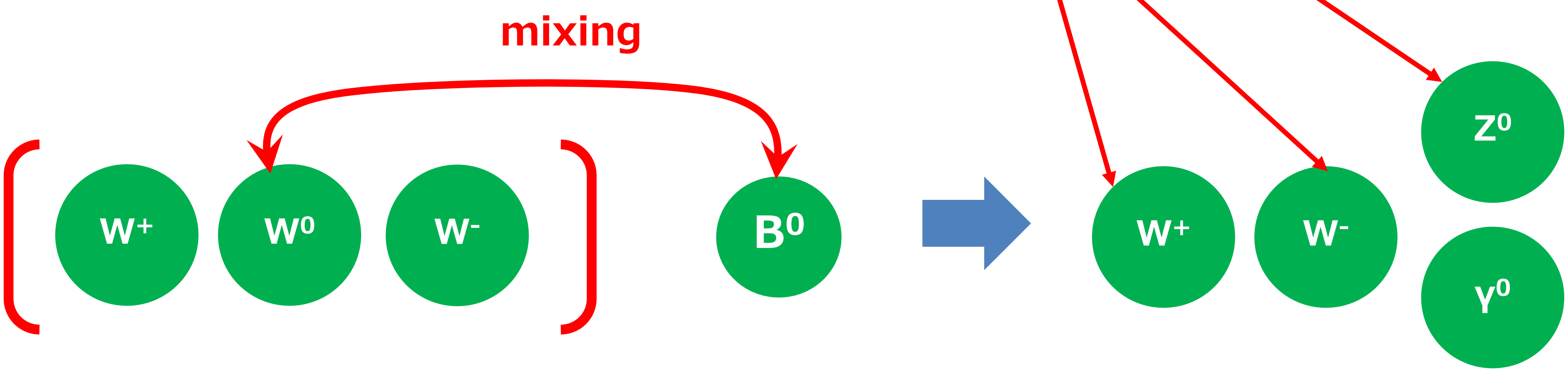
Symmetry: Local $SU(2)_I \times U(1)_Y$



$$V(\Phi) = \mu^2 \Phi^\dagger \Phi + \lambda (\Phi^\dagger \Phi)^2$$

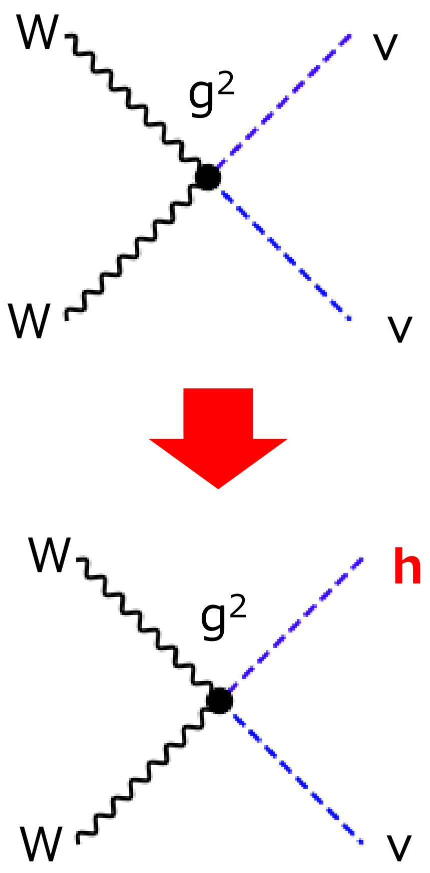
$$\langle \phi^0 \rangle = v$$

$$SU(2)_L \times U(1)_Y \to U(1)_{\mathrm{em}}$$



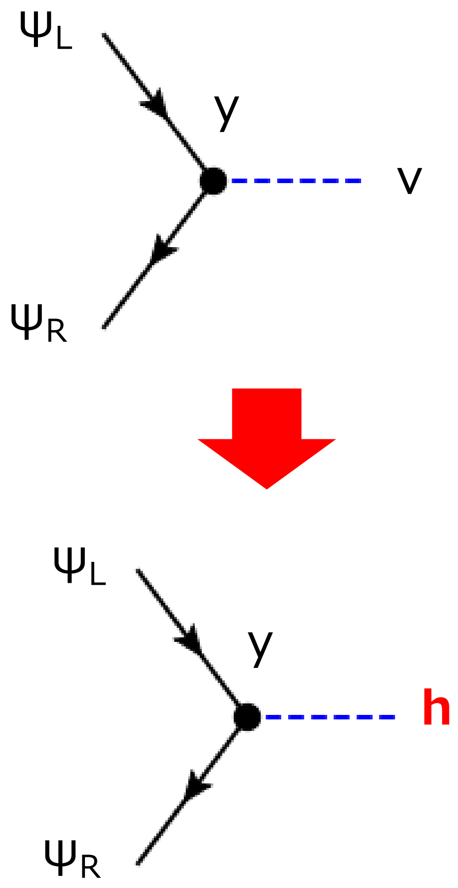
Origin of Mass

Kin. term $|D_\mu \Phi|^2$



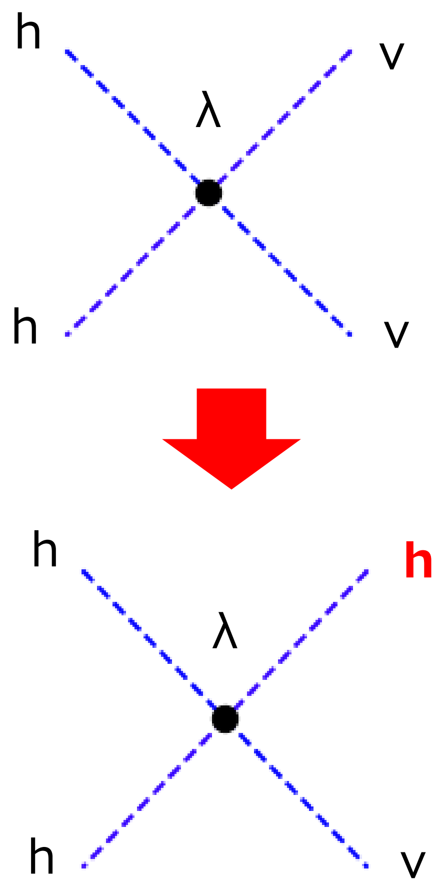
$$g_{hWW} \propto \frac{m_W^2}{v}$$

Yukawa $y \bar{\Psi}_L \Phi \Psi_R$



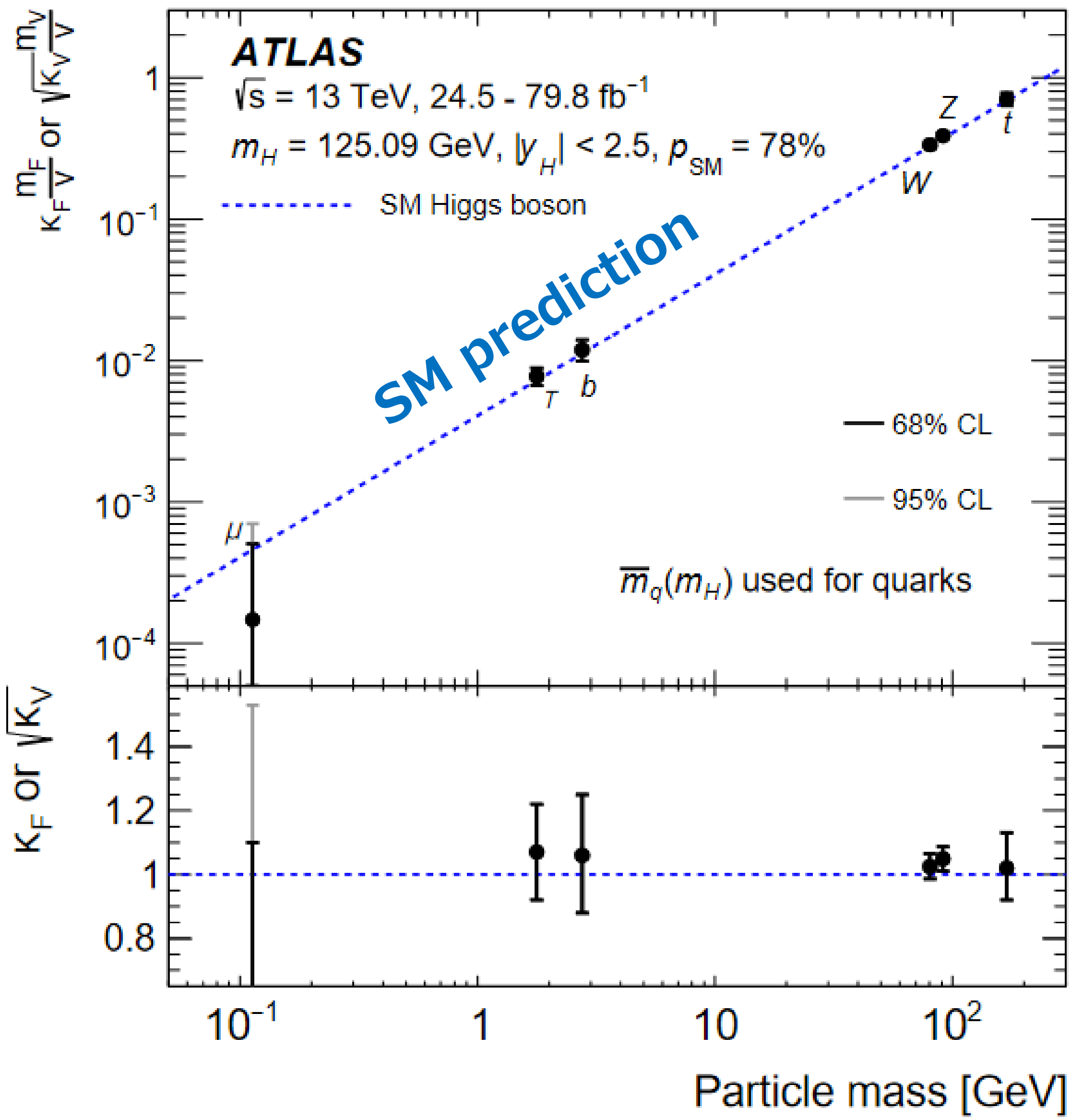
$$g_{hff} \propto \frac{m_f}{v}$$

Potential $V(\Phi)$



$$g_{hhh} \propto \frac{m_h^2}{v}$$

$$\kappa_X \equiv \frac{g_{hXX}^{\mathrm{exp}}}{g_{hXX}^{\mathrm{SM}}}$$



ATLAS-CONF-2021-053

Parameter	(a) $B_{i.} = B_{u.} = 0$
κ_Z	0.99 ± 0.06
κ_W	1.06 ± 0.06
κ_b	0.87 ± 0.11
κ_t	0.92 ± 0.10
κ_μ	$1.07\ ^{+0.25}_{-0.30}$
κ_τ	0.92 ± 0.07
κ_γ	1.04 ± 0.06
$\kappa_{Z\gamma}$	$1.37\ ^{+0.31}_{-0.37}$
κ_g	$0.92\ ^{+0.07}_{-0.06}$
$B_{i.}$	-
$B_{u.}$	-

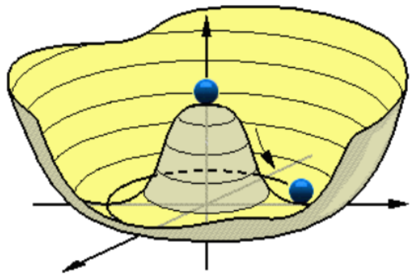
Great success of the standard model.

Contents

Higgs Problems

- So far, the SM Higgs sector can successfully describe current experimental data.

$$V(\Phi) = -\mu^2|\Phi|^2 + \lambda|\Phi|^4$$



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Origin of the negative mass term

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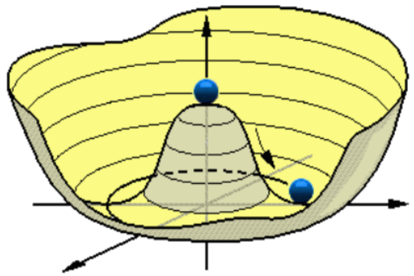

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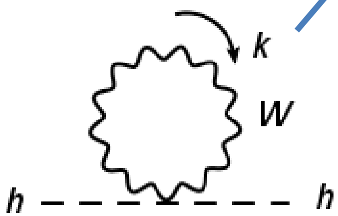
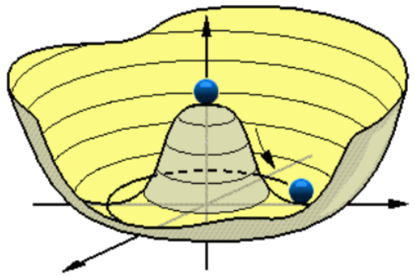
Quadratic divergence



$$m_h^2 \sim \frac{\Lambda^2}{16\pi^2} \gg (125\ \mathrm{GeV})^2$$



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One doublet?

Any other representations?

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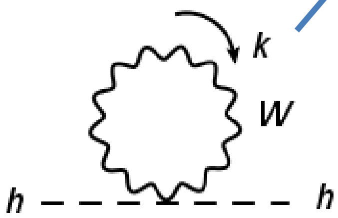

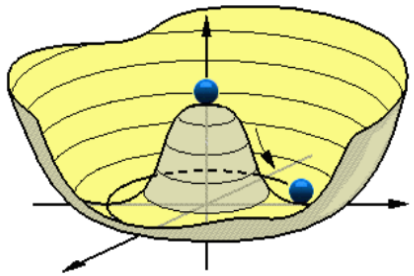

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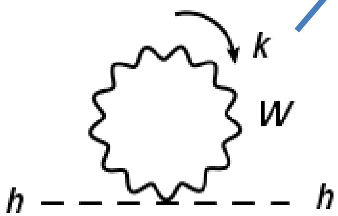

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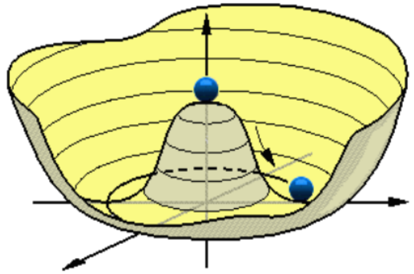

Yukawa coupling? $\frac{y_e}{y_t} \sim 10^{-5}$

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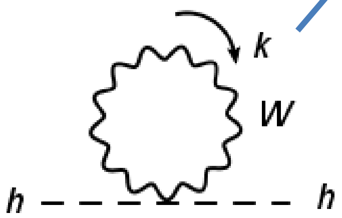

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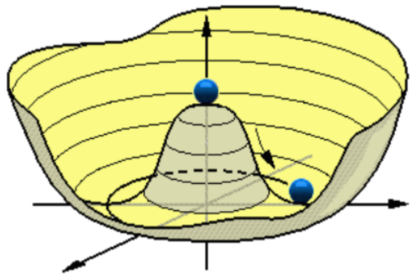


Yukawa coupling? $\dfrac{y_e}{y_t} \sim 10^{-5}$

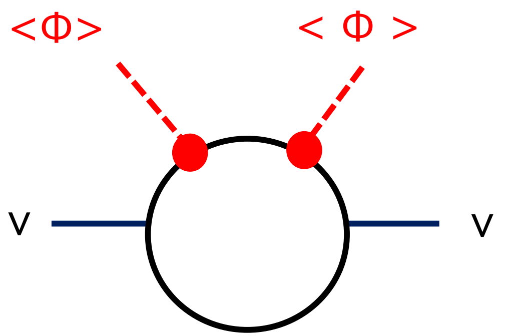
The Higgs sector is the center of the problem in the SM.

There should be new dynamics behind the Higgs sector.

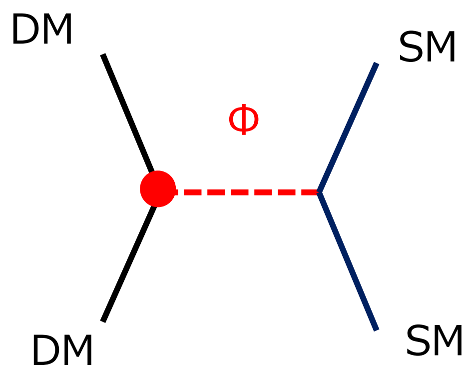
Higgs sector and BSM phenomena

- Phenomena cannot be explained in the SM.

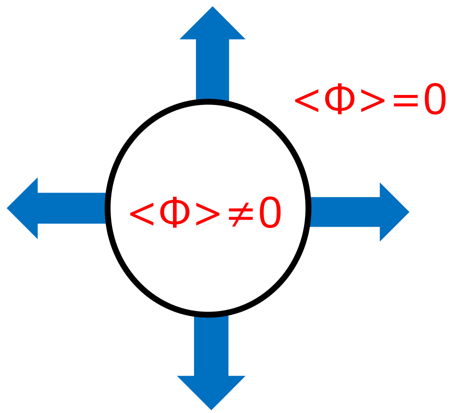
Neutrino mass



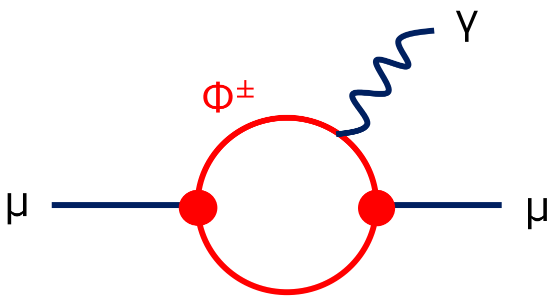
Dark matter



Baryon asymmetry of Universe

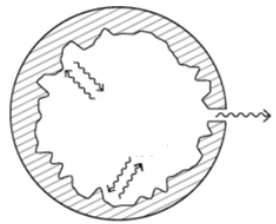


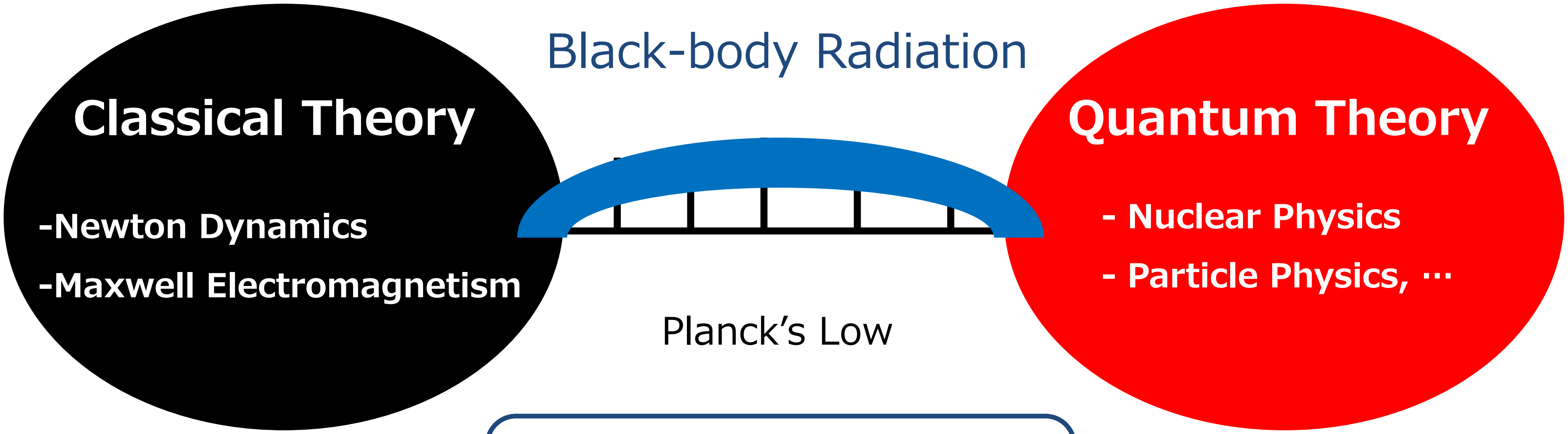
Flavor anomaly $(g\text{-}2)_\mu$



Higgs physics can strongly be related to BSMs.

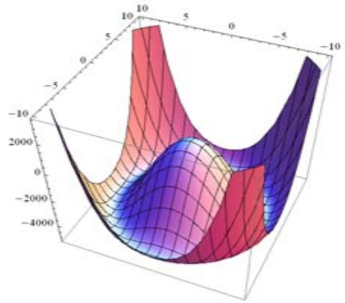
Paradigm Shift in Early 20th Century





$$u(\nu, T) = \frac{8\pi\nu^2}{c^3}\frac{h\nu}{\exp(h\nu/k_B T)-1}$$

Paradigm Shift in Early 21st Century



Higgs Physics

Standard Model

- -Gauge Principle
- -Higgs Mechanism

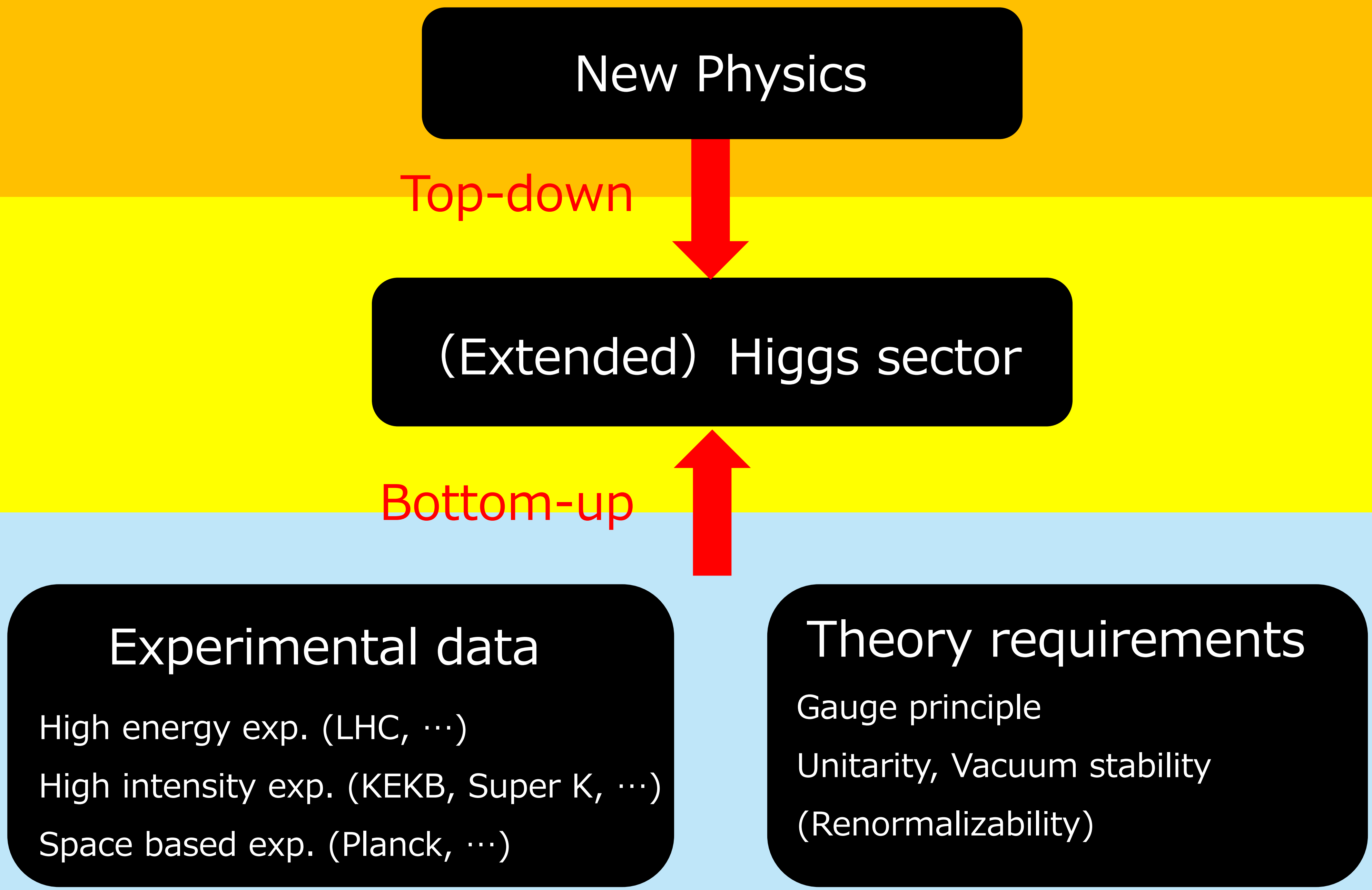
New Physics

- New dynamics
- New symmetries
- Unifications, …

$$V(\Phi) = -\mu^2|\Phi|^2 + \lambda|\Phi|^4$$

Higgs as a Probe of New Physics!!

Higgs as a window to New Physics



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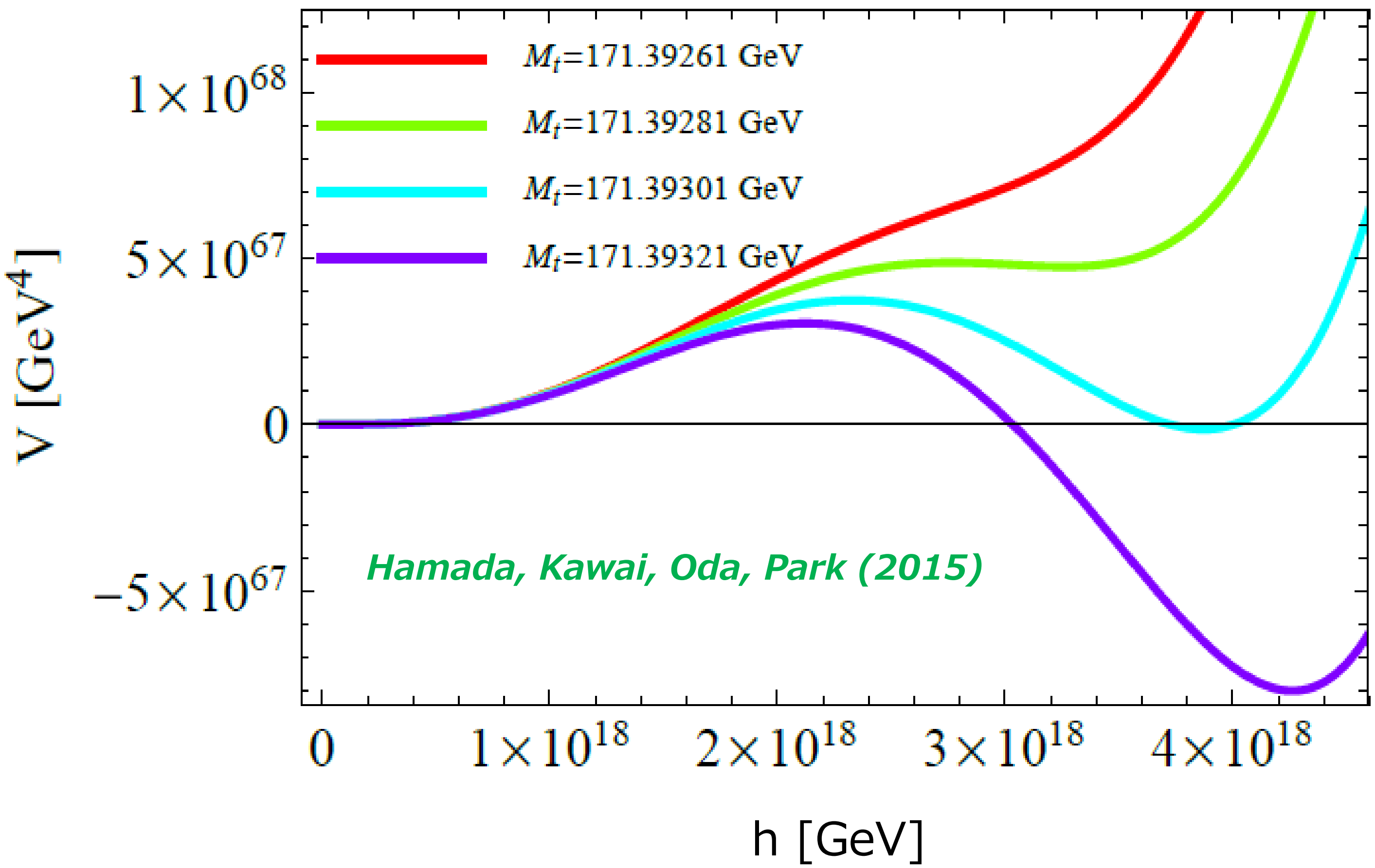
Yuta Hamada (Harvard U.), Hikaru Kawai (National Taiwan U.),
Kiyoharu Kawana (Seoul National U.), Kin-ya Oda (Tokyo Woman's Christian U.), KY
2008.08700 [hep-ph], 2102.04617 [hep-ph] + paper in progress,

Implication of the 125 GeV Higgs mass

Mass (Pole from cross-section measurements) $m = 172.5 \pm 0.7$ GeV

PDG



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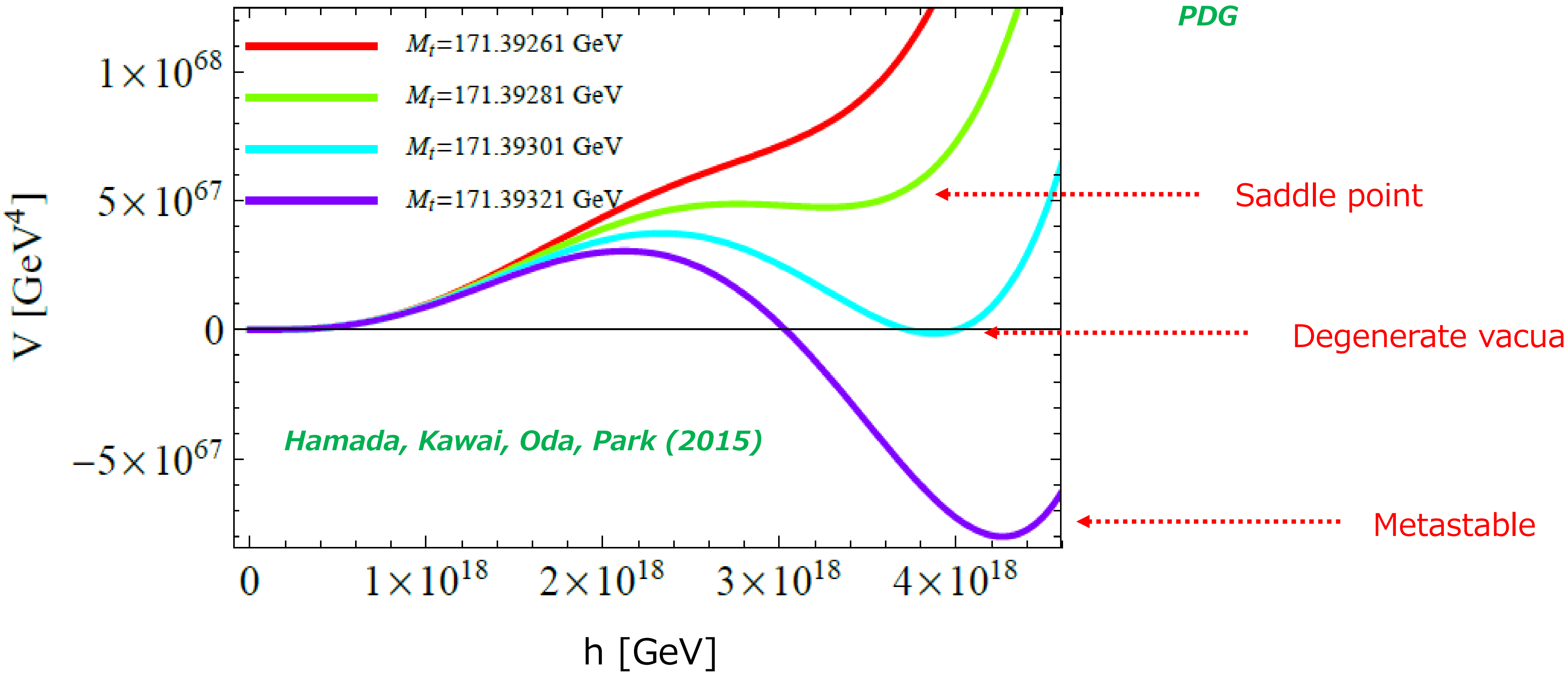
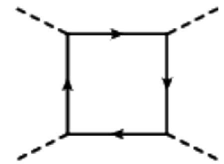


Implication of the 125 GeV Higgs mass

$$V_{\rm eff} = \frac{\lambda_{\rm eff}(h)}{4} h^4$$

@ h » v, μ = h

$$\mu \frac{d\lambda}{d\mu} = \frac{1}{16\pi^2}(24\lambda^2 - 6y_t^4 + \cdots)$$



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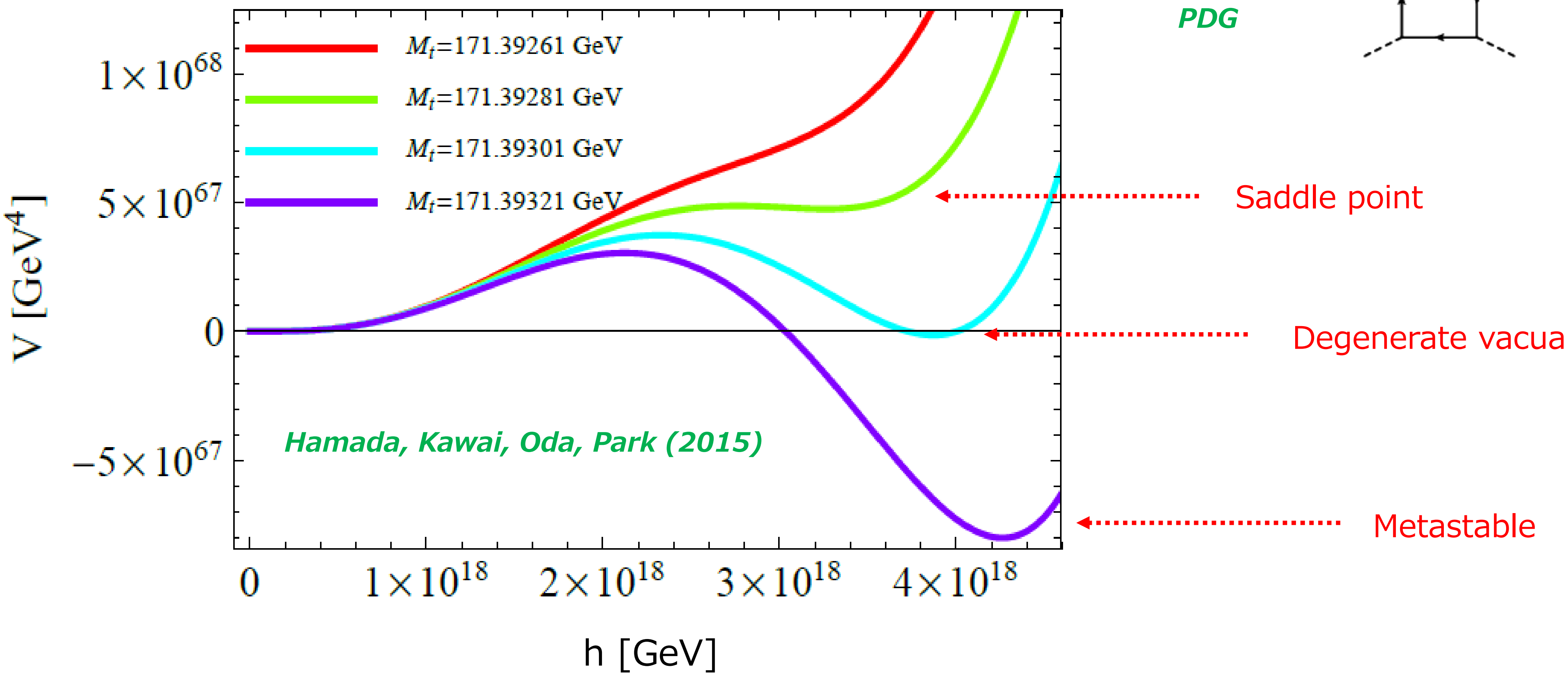


Froggatt & Nielsen (1995)

ELSEVIER

Physics Letters B 368 (1996) 96–102

PHYSICS LETTERS B

Standard model criticality prediction top mass 173 ± 5 GeV and Higgs mass 135 ± 9 GeV

C.D. Froggatt[a], H.B. Nielsen[b]

[a] *Department of Physics and Astronomy, Glasgow University, Glasgow G12 8QQ, Scotland, UK*

[b] *The Niels Bohr Institute, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark*

Received 4 November 1995

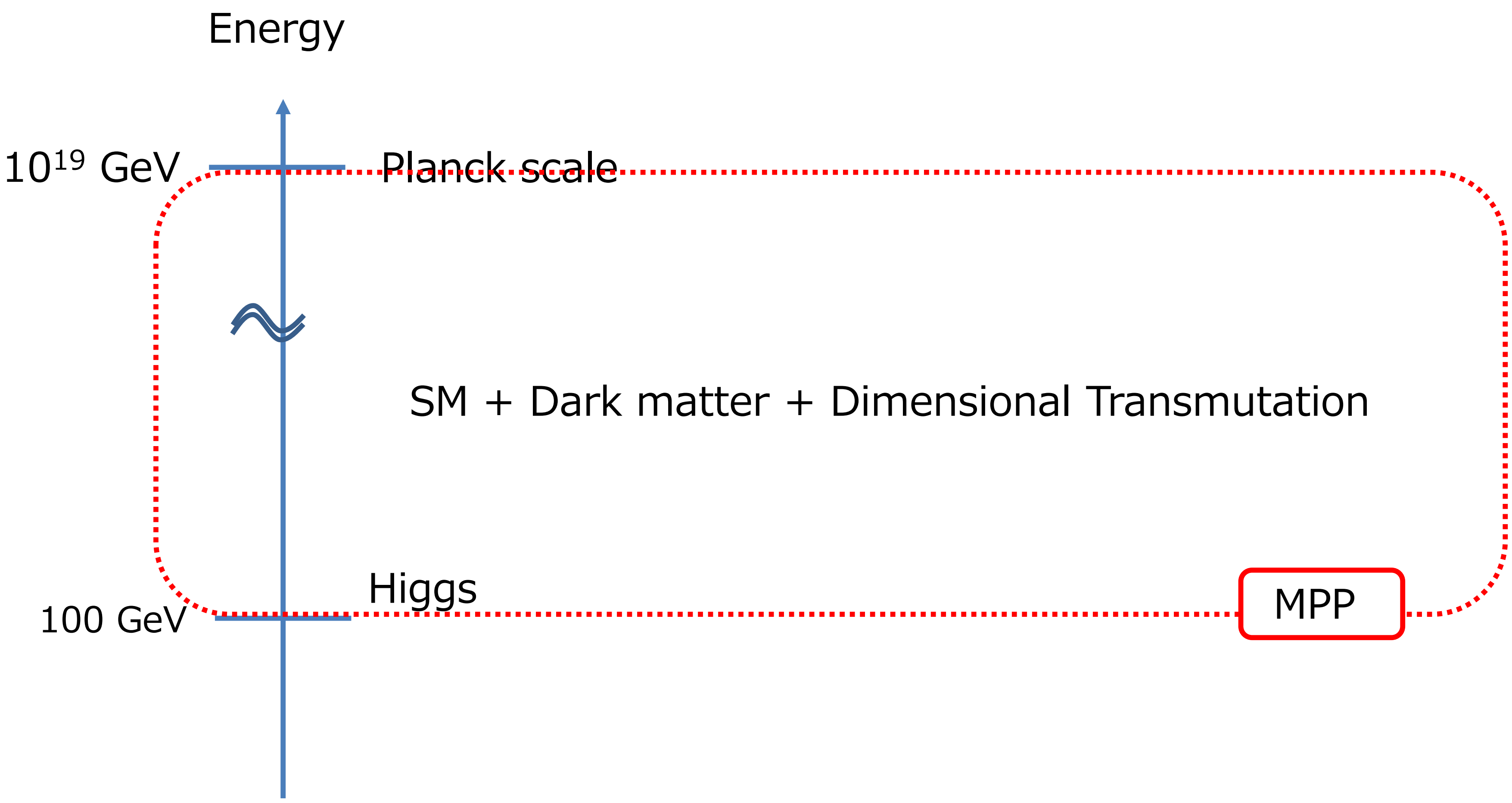
Editor: P.V. Landshoff

They predicted the Higgs mass in 1995!!

The Higgs potential is realized at a critical point?

→ Multicritical point principle (MPP)

Our Scenario



We proposed a minimal model to realize the scenario based on the MPP framework.

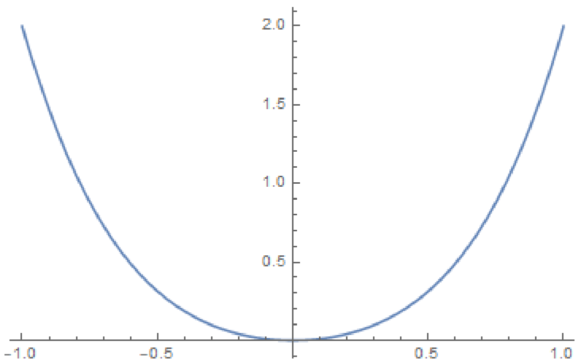
Multicritical point principle (MPP)

Froggatt, Nielsen (1995)

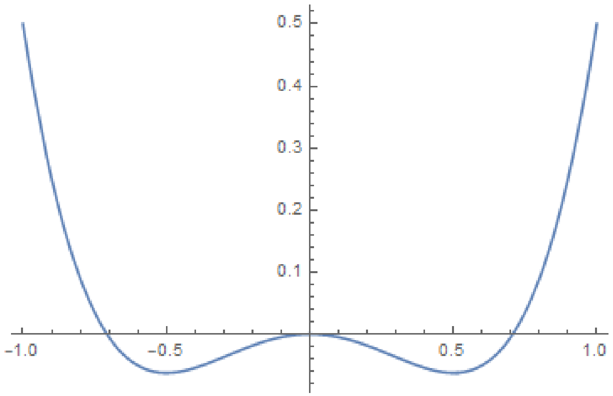
MPP: More parameters in the effective potential are tuned to a set of critical values, which is more likely to be realized by nature.

Examples: $V = \mu^2|H|^2 + \lambda|H|^4$

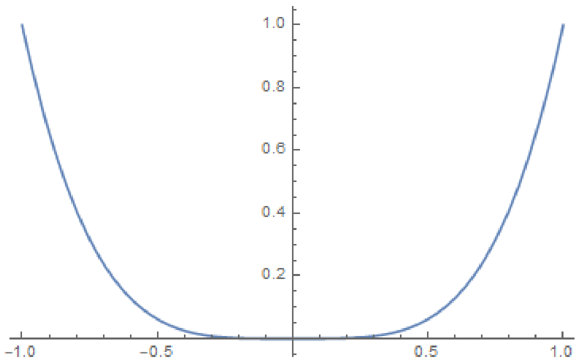
$\mu^2 > 0$: Stable



$\mu^2 < 0$: SSB



$\mu^2 = 0$: Critical point



Classical Scale Invariance (CSI)

CSI can be understood as a special realization of the MPP.

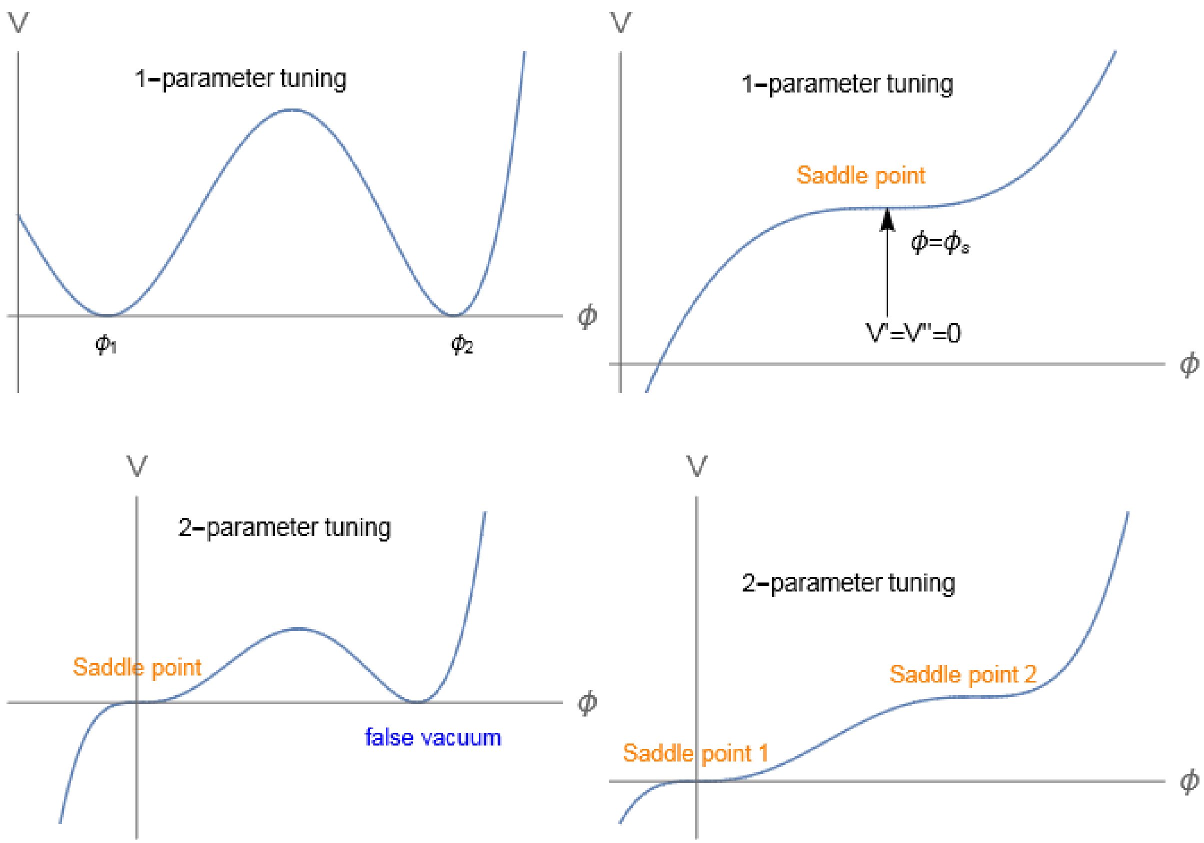
Multicritical point principle (MPP)

Froggatt, Nielsen (1995)

MPP: More parameters in the effective potential are tuned to a set of critical values, which is more likely to be realized by nature.

Examples:

Kawai, Kawana, 2107.10720 [hep-th]

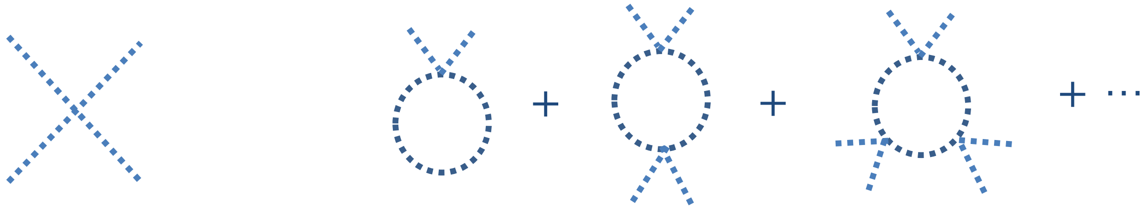


Dimensional transmutation

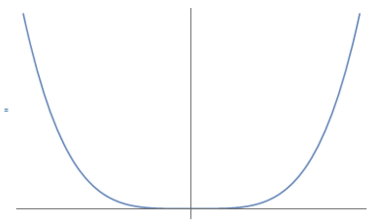
Coleman, Weinberg (1972)

Massless (CSI) Φ⁴ theory: $V_{\rm tree} = \frac{\lambda}{4!}\phi^4$

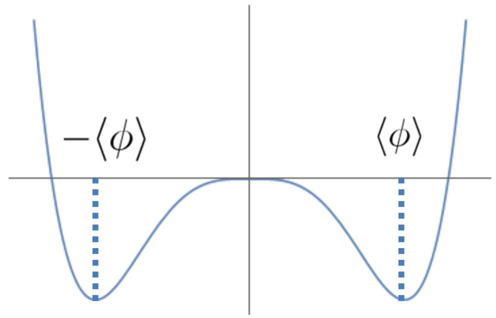
Eff. potential at 1-loop:



$$V_{\rm eff} = \underbrace{\frac{\lambda}{4!}\phi_c^4}_{\text{tree}} + \underbrace{\frac{m_\phi^4}{64\pi^2}\left[\ln\frac{m_\phi^2}{\mu^2} - \frac{3}{2}\right]}_{\text{1-loop}} \qquad m_\phi^2 = \frac{\lambda}{2}\phi_c^2$$



Dimensional transmutation



$$\langle\phi\rangle \propto M_{\rm pl}\exp\left(-\frac{16\pi^2}{3\lambda} + \frac{1}{2}\right) \qquad (\mu = M_{\rm pl})$$

However, it does not work….

2-scalar model

Bornholdt, Tetradis, Wetterich (1994)

Jennifer, Adams, Tetradis (1995)

Φ and S with a Z_2 symmetry S → -S and <S> = 0

$$V_{\rm tree} = \frac{\lambda}{4!}\phi^4 + \frac{\lambda_S}{4!}S^4 + \frac{\lambda_{\phi S}}{4}\phi^2 S^2$$

$$m_\phi^2 = \frac{\lambda}{2}\phi_c^2$$

$$m_S^2 = \frac{\lambda_{\phi S}}{2}\phi_c^2$$

Negligible if $\lambda \ll \lambda_{\Phi S}$

$$V_{\rm eff} = \frac{\lambda}{4!}\phi_c^4 + \frac{m_\phi^4}{64\pi^2}\left[\ln\frac{m_\phi^2}{\mu^2} - \frac{3}{2}\right] + \frac{m_S^4}{64\pi^2}\left[\ln\frac{m_S^2}{\mu^2} - \frac{3}{2}\right]$$

Dimensional transmutation: $\langle\phi\rangle \propto M_{\rm pl}\exp\left(-\frac{16\pi^2}{3}\frac{\lambda}{\lambda_{\phi S}^2} + \frac{1}{2}\right)$

Taking $\lambda/\lambda_{\Phi S}^2 = O(0.1)$, the EW scale is generated from the Planck scale!

In addition, S can be identified as a dark matter candidate!

Maximal Criticality

Kawai, Kawana, 2107.10720 [hep-th]

Generally, the effective potential for Φ is written as

$$V_{\text{eff}} = \mu_1^3 \phi_c + \frac{\mu_2^2}{2}\phi_c^2 + \frac{\mu_3}{3!}\phi_c^3 + \frac{\lambda_\phi}{4!}\phi_c^4 + \frac{m_S^4}{64\pi^2}\left[\ln\frac{m_S^2}{\mu^2} - \frac{3}{2}\right]$$

We can take μ = M at which λ_Φ term vanishes.

$$V_{\text{eff}} = \mu_1^3 \phi_c + \frac{\mu_2^2}{2}\phi_c^2 + \frac{\mu_3}{3!}\phi_c^3 + \frac{\lambda_{\phi S}^2}{64\pi^2}\ln\frac{\phi_c^2}{M^2}$$

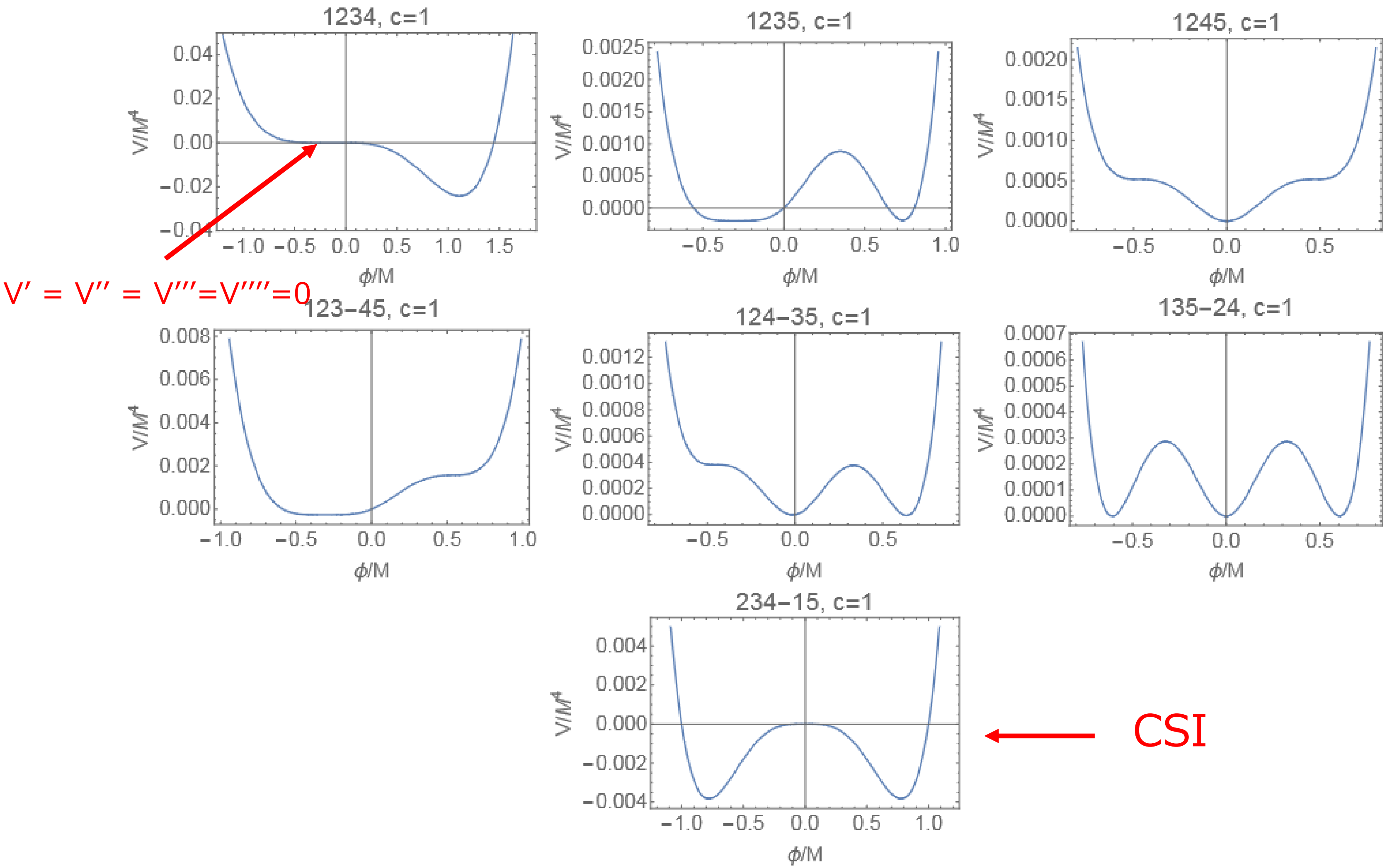
- The shape of the potential is determined by 3 parameters e.g., μ_1, μ_2 and μ_3.
- This potential generally has 5 extrema.

➡ We can take triple criticality as the maximal critical point.

Maximal Criticality

Kawai, Kawana, 2107.10720 [hep-th]

There are 7 independent triply critical points.



We focus on CP 1234, which may realize the strongly 1st order PT → Gravitational wave?

CP 1234

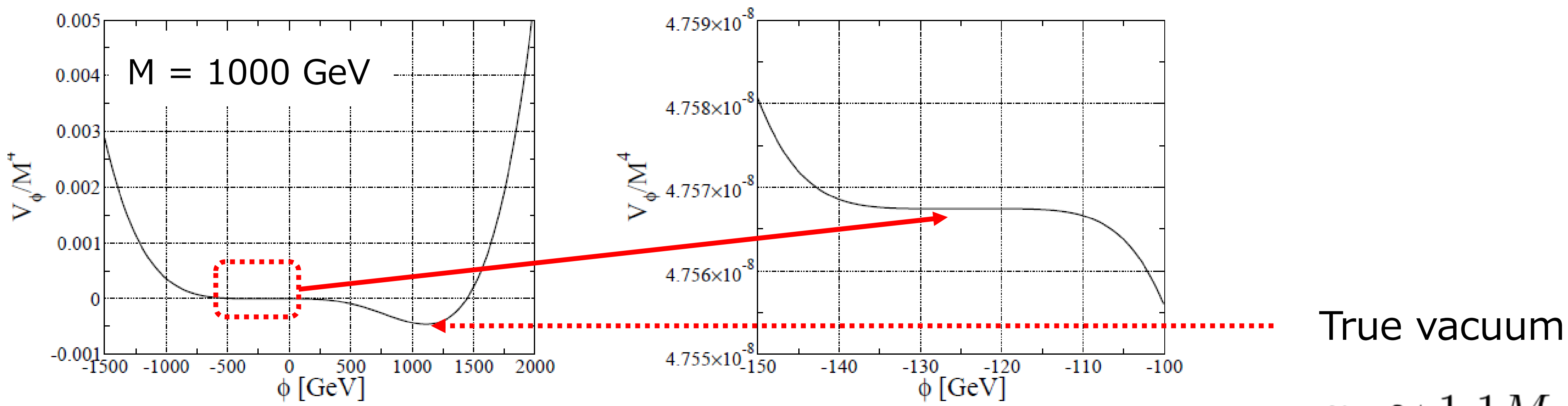
CP 1234: $$\left.\frac{dV_{\rm eff}}{d\phi}\right|_{\phi\to\phi_S} = \left.\frac{d^2V_{\rm eff}}{d\phi^2}\right|_{\phi\to\phi_S} = \left.\frac{d^3V_{\rm eff}}{d\phi^3}\right|_{\phi\to\phi_S} = \left.\frac{d^4V_{\rm eff}}{d\phi^4}\right|_{\phi\to\phi_S} = 0.$$

$$\kappa = \frac{3}{16\pi^2}\lambda_{\phi S}^2$$

$$\mu_1^3 = -\frac{\kappa M^3}{18 e^{25/4}}, \quad \mu_2^2 = -\frac{\kappa M^2}{4 e^{25/6}}, \quad \mu_3 = -\frac{\kappa M}{e^{25/12}}, \quad \phi_S = -\frac{M}{e^{25/12}}$$

$$\bar{\phi} = \frac{\phi}{M}$$

$$V_{\rm eff} = \kappa M^4 \left[-\frac{\bar{\phi}_c}{18 e^{25/4}} - \frac{\bar{\phi}_c^2}{8 e^{25/6}} - \frac{\bar{\phi}_c^3}{6 e^{25/12}} + \frac{\bar{\phi}_c^4}{48}\ln \bar{\phi}_c^2 \right]$$



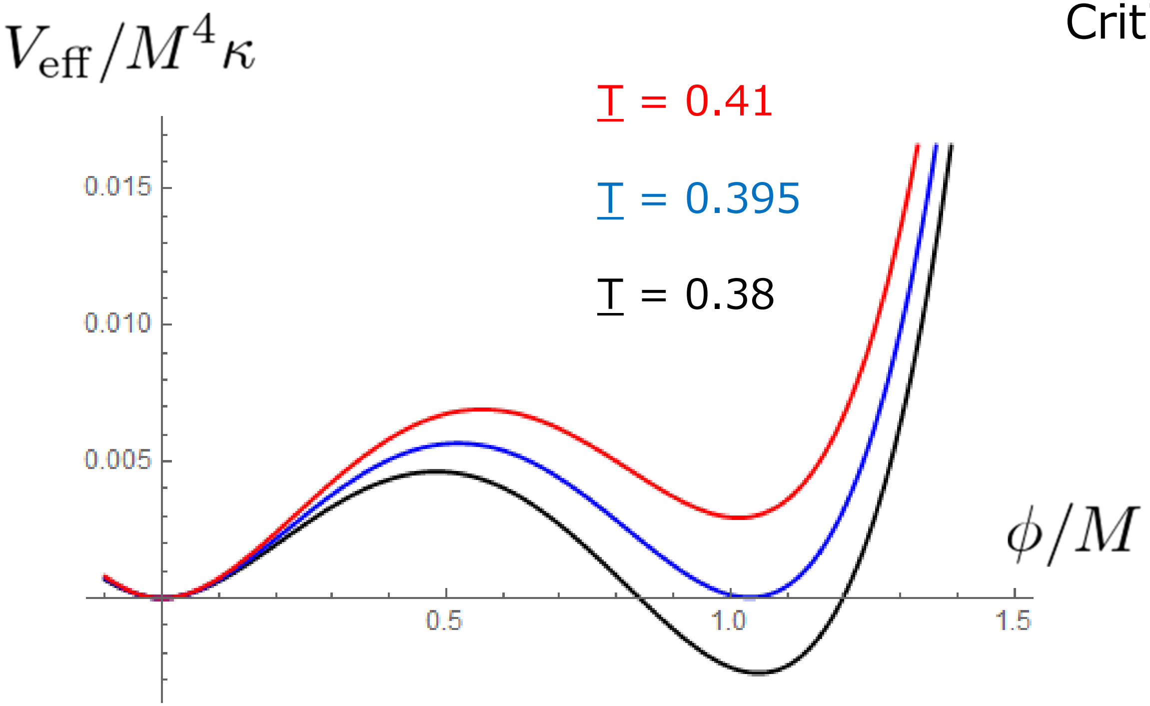
$$v_\phi \simeq 1.1 M$$

Potential at finite temperature

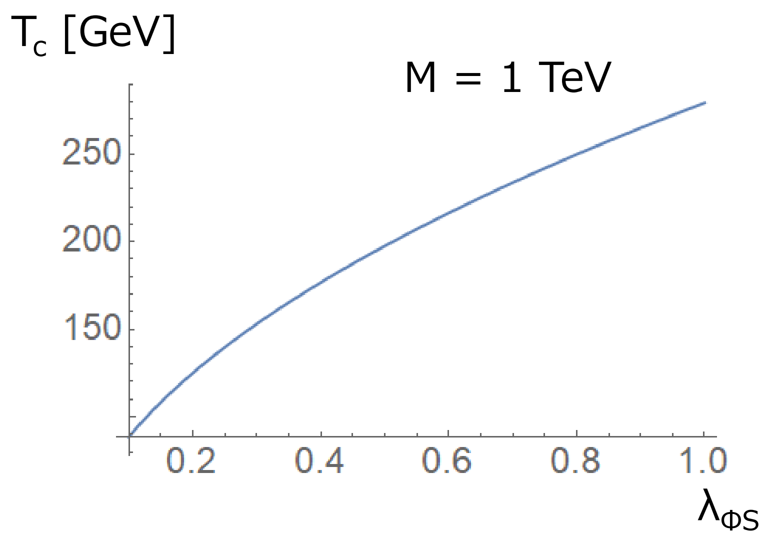
$$\bar{\phi} = \frac{\phi}{M} \qquad \bar{T} = \frac{T}{M}\frac{1}{\sqrt{2\pi}}\left(\frac{3}{\kappa}\right)^{1/4} = \frac{T}{M}\sqrt{\frac{2}{\lambda_{\phi S}}}$$

$$V_{\rm eff}(\bar{\phi}, T) = V_{\rm eff}(\bar{\phi}, T=0) + \Delta V_{\rm eff}(\bar{\phi}, T)$$
$$= \kappa M^4 \left[-\frac{\bar{\phi}}{18 e^{25/4}} - \frac{\bar{\phi}^2}{8 e^{25/6}} - \frac{\bar{\phi}^3}{6 e^{25/12}} + \frac{\bar{\phi}^4}{48} \ln \bar{\phi}^2 + \frac{2\bar{T}^4}{3} \int_0^\infty dx\, x^2 \ln\left(1 - e^{-\sqrt{x^2 + \bar{\phi}/\bar{T}^2}}\right) \right]$$

The shape of the potential is determined only by the $\underline{T}$ parameter!



Critical temperature $\underline{T}_c$ ~ 0.395!



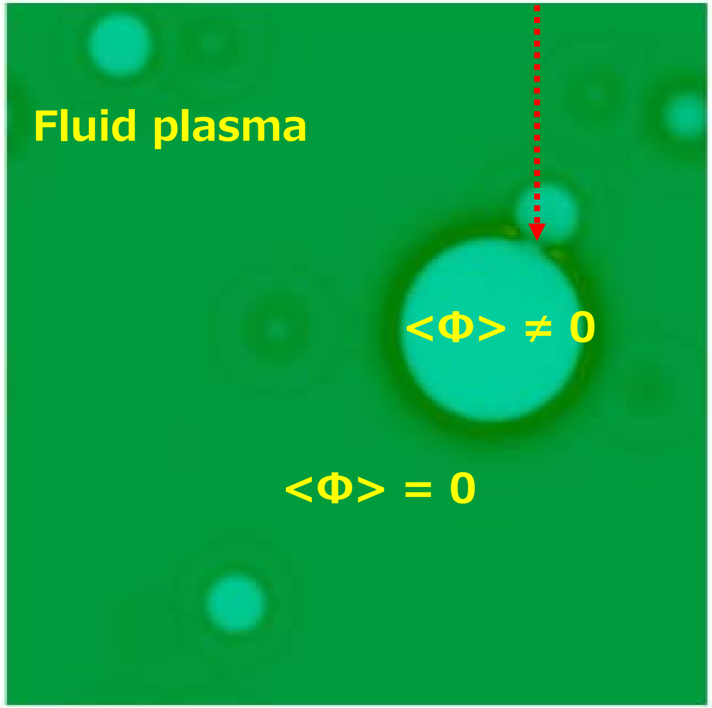
1st order phase transition can be realized!

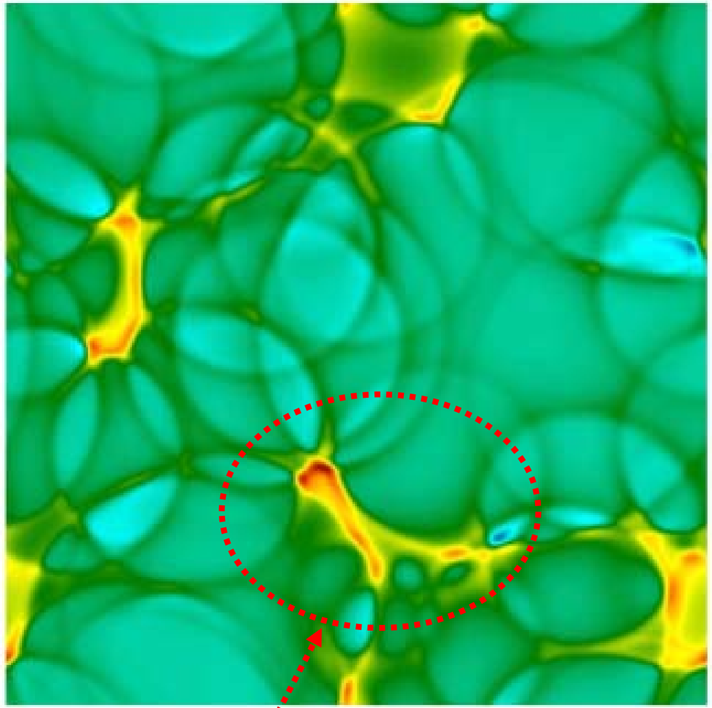
Gravitational Waves from 1st OPT

Bubble collision

Energy density of fluid

Hindmarsh, Huber, Rummukainen, Weir (2013)





Grojean, Servant (2007)

Leitao, Megevand, Sanchez (2012)

Jinno, Nakayama, Takimoto (2016)

Hashino, Kakizaki, Kanemura, Matsui (2016), ⋯.

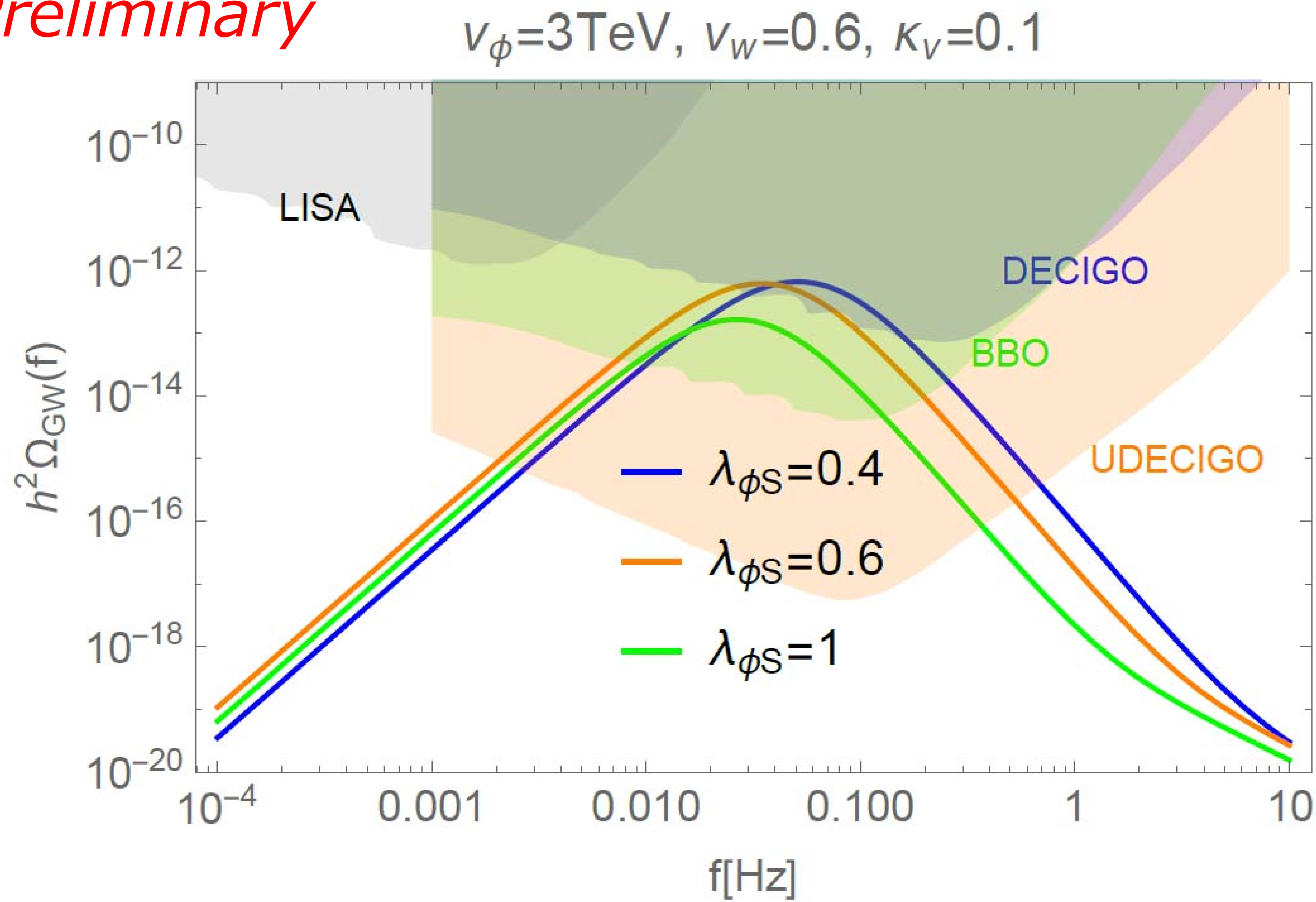
Sound waves (Compressed waves)

Turbulence of plasma

Gravitational Waves

Hamada, Kawai, Kawana, Oda, KY, in progress

Preliminary



Implementation to the SM

$$\mathcal{L} = \mathcal{L}_{\rm SM}^{\rm w/o\ pot.} - V_{\rm MPP}(H, \phi, S) \qquad V_{\rm MPP} = V_{\rm CSI} + V_{\phi}^{\rm CP-1234}$$

Trigger the EWSB after Φ gets the VEV.

$$V_{\rm CSI} = \frac{\lambda_H}{2}(H^\dagger H)^2 + \frac{\lambda_S}{4!}S^4 - \frac{\lambda_{\phi H}}{2}\phi^2(H^\dagger H) + \frac{\lambda_{\phi S}}{4}\phi^2 S^2 + \frac{\lambda_{SH}}{2}S^2(H^\dagger H)$$

$$v_H = v_\phi \sqrt{\frac{\lambda_{\phi H}}{\lambda_H}}$$ ~ 246 GeV

$$m_h^2 \simeq v_H^2 \lambda_H$$ ~ (125 GeV)^2

$$m_H^2 \simeq 0.23\,\kappa\, v_\phi^2 \simeq \left(130\ {\rm GeV} \times \frac{\lambda_{\phi S}}{1} \times \frac{v_\phi}{2\ {\rm TeV}}\right)^2$$

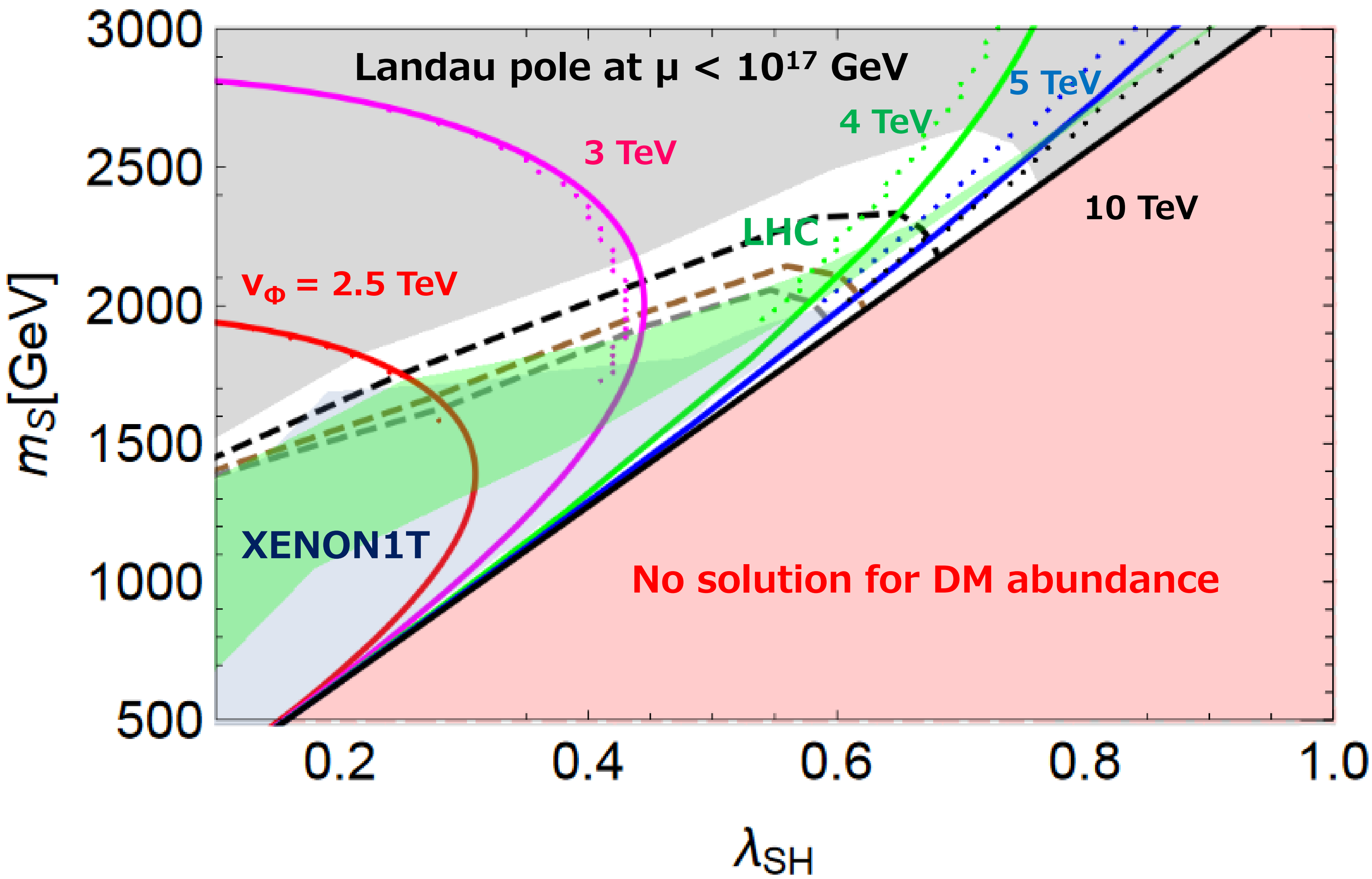
Only 3 free parameters! (m_S, λ_{HS}, v_Φ)

DM mass DM-Higgs coupling

Phenomenology

Hamada, Kawai, Oda, KY, 2008.08700 [hep-ph]

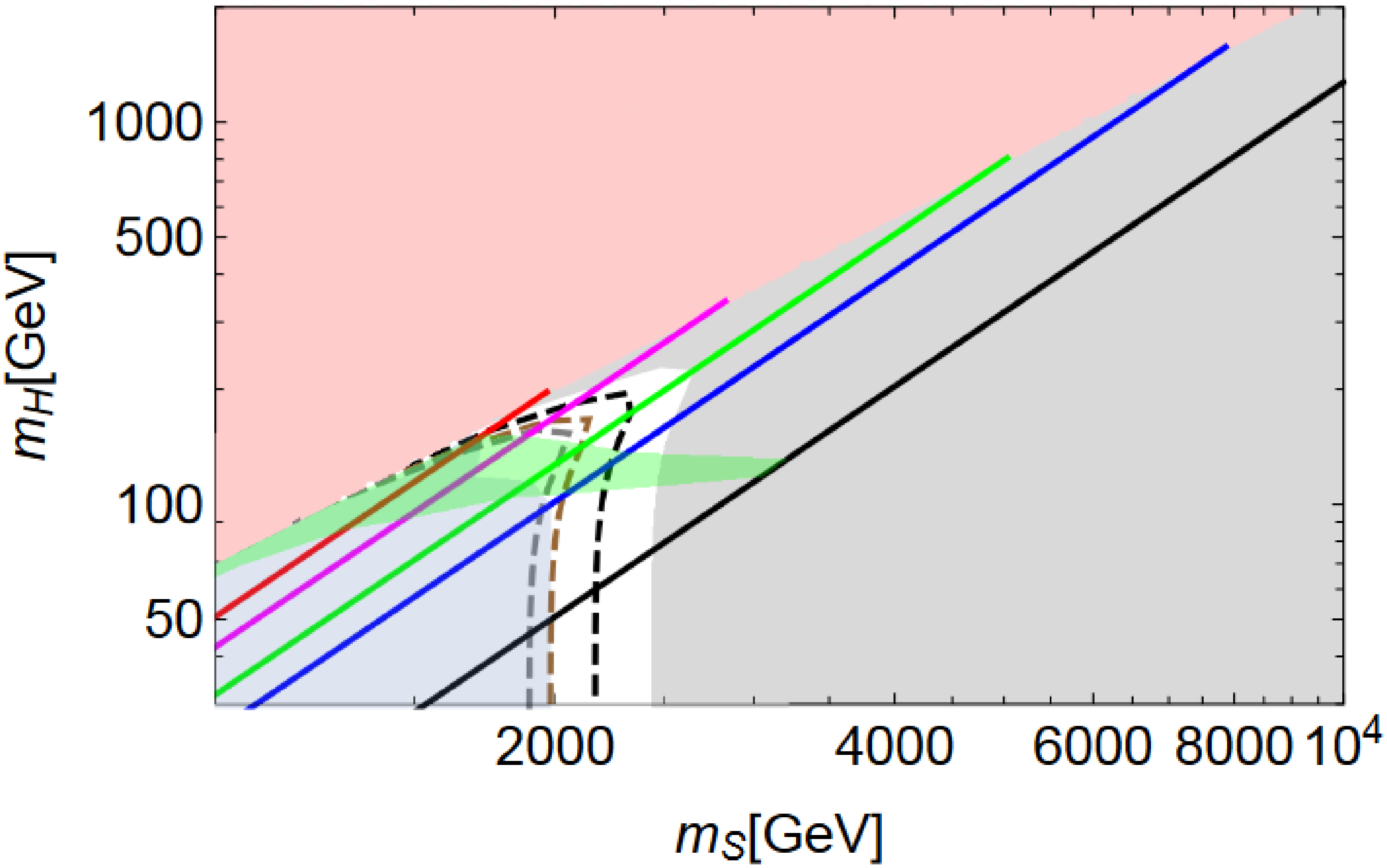
*This result is based on the other CP, but the result is almost the same.



Phenomenology

Hamada, Kawai, Oda, KY, 2008.08700 [hep-ph]

*This result is based on the other CP, but the result is almost the same.



Additional Higgs boson mass is predicted to be at around 150-200 GeV.

Contents

I. What is the Higgs boson?

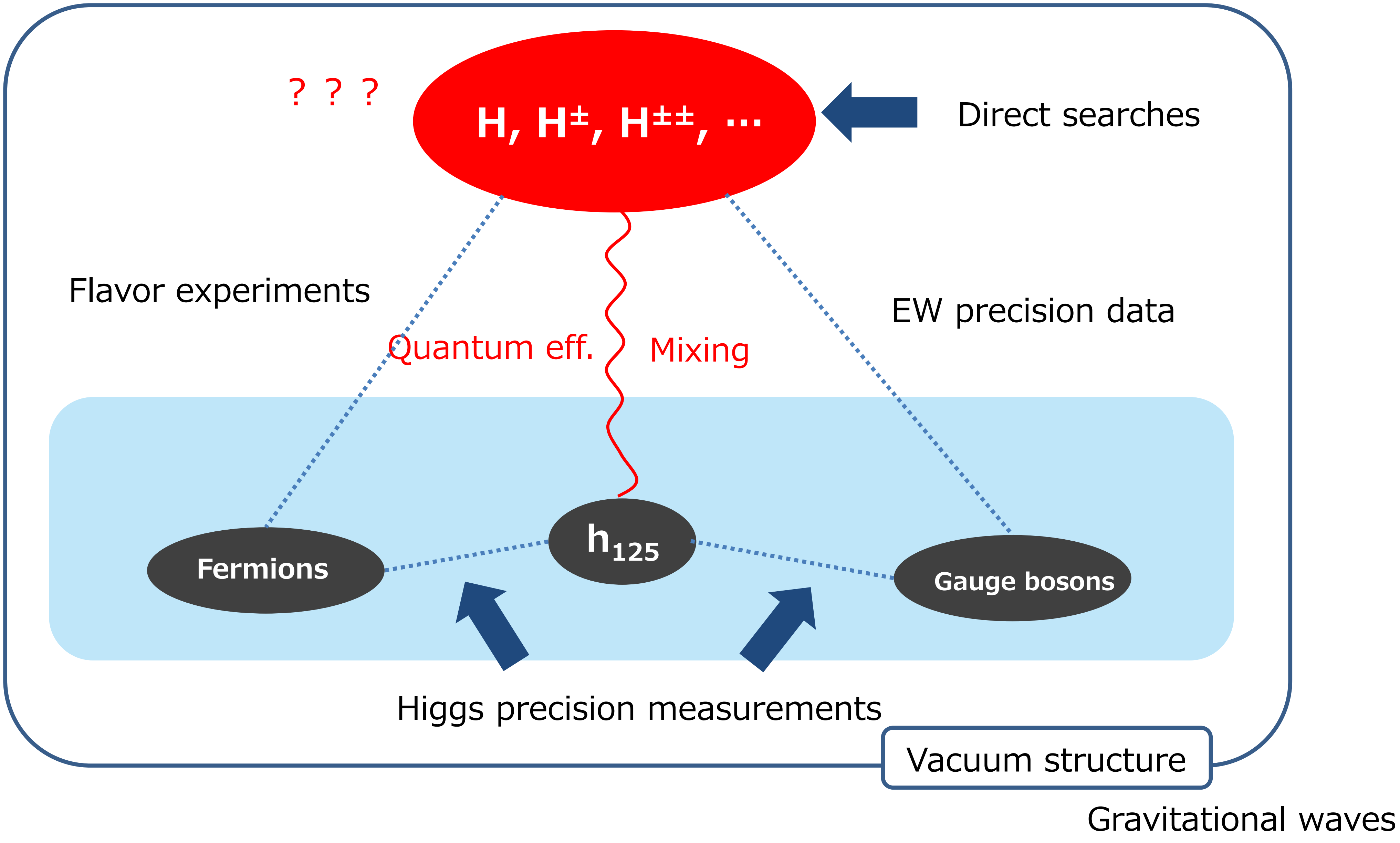
II. Why is Higgs Physics important?

III. How can we determine the Higgs sector?

- Bottom-up approach
- Top-down approach

IV. Summary

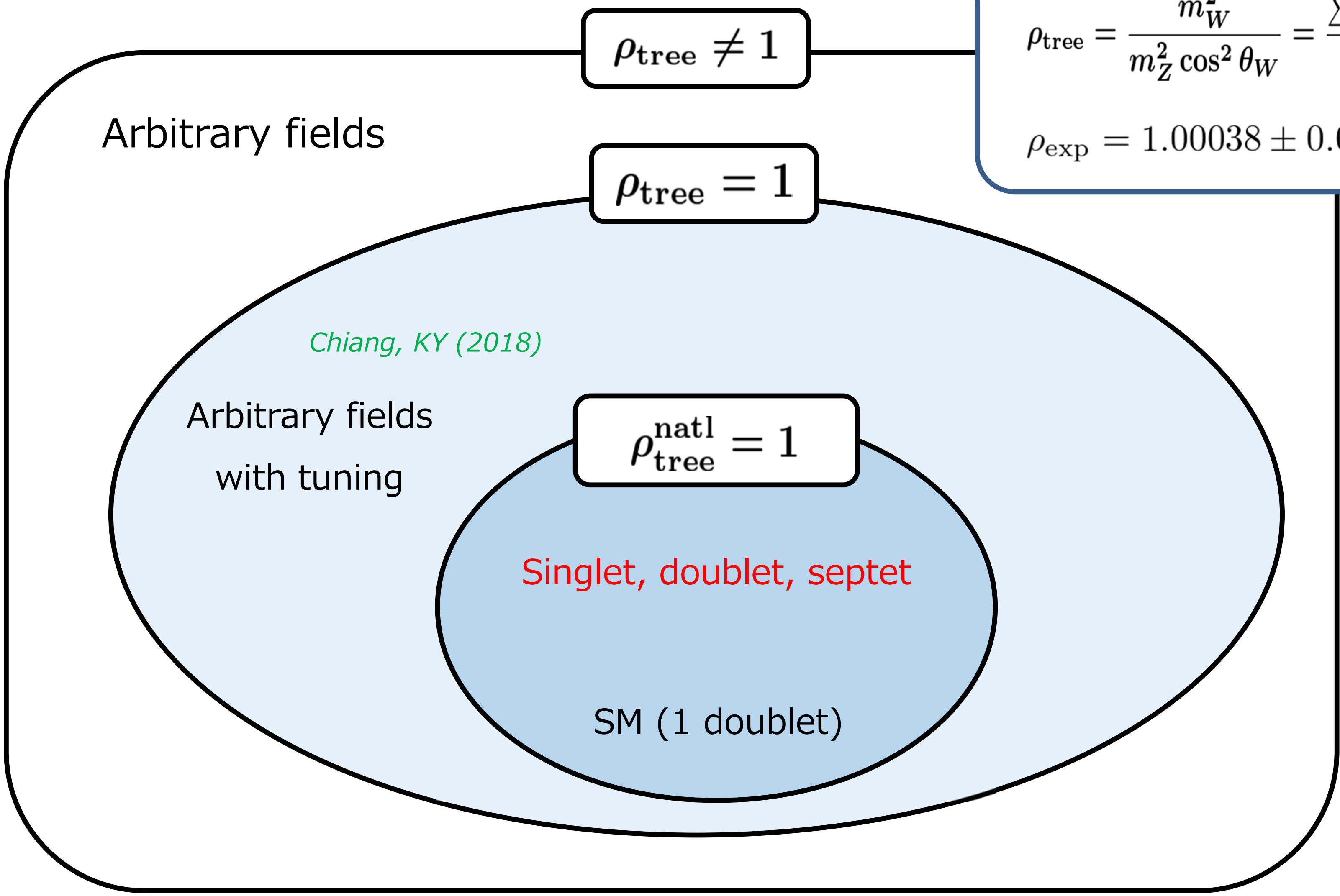
Exploring the Higgs sector



Constraints from EWPO

$$\rho_{\text{tree}} = \frac{m_W^2}{m_Z^2 \cos^2\theta_W} = \frac{\sum_b v_b^2 [T_b(T_b+1) - Y_b^2]}{2\sum_a v_a^2 Y_a^2}$$

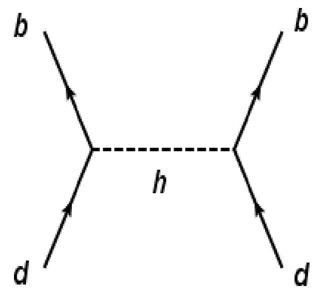
$$\rho_{\text{exp}} = 1.00038 \pm 0.0002$$



Constraints from Flavor Experiments

Multi-doublet structures introduces FCNCs

$$\mathcal{L}_Y = \bar{Q}_L(Y_1\Phi_1 + Y_2\Phi_2)d_R + \text{h.c.}$$



$M \gtrsim \mathcal{O}(100)$ TeV
for $\mathcal{O}(0.1)$ coupling

$$\Rightarrow \quad M = v_1 Y_1 + v_2 Y_2$$ Mass matrix

$$\Rightarrow \quad Y = \langle h_1|h\rangle Y_1 + \langle h_2|h\rangle Y_2$$ Interaction matrix

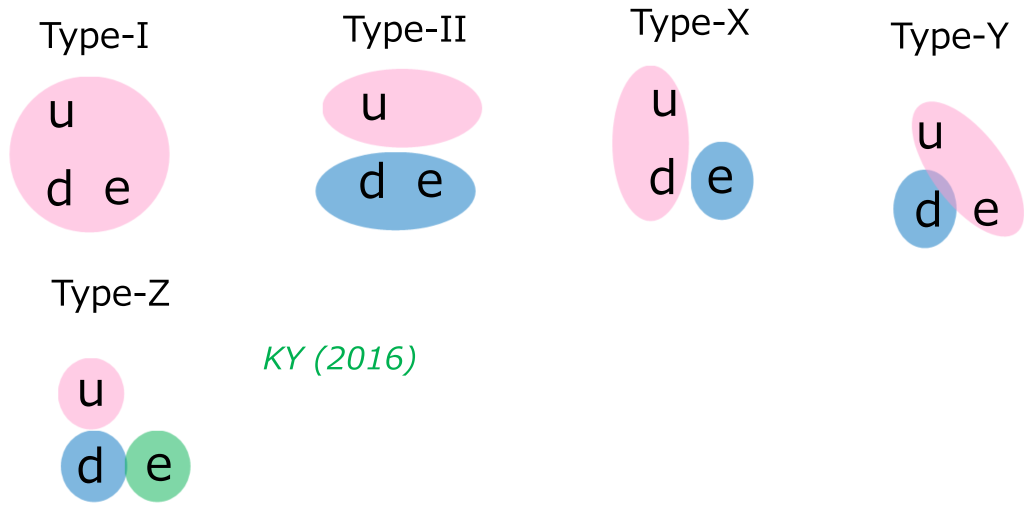
Generally $M \not\propto Y$ ⇒ FCNC!

Barger, Hewett, Phillips (1990), Grossman (1994)

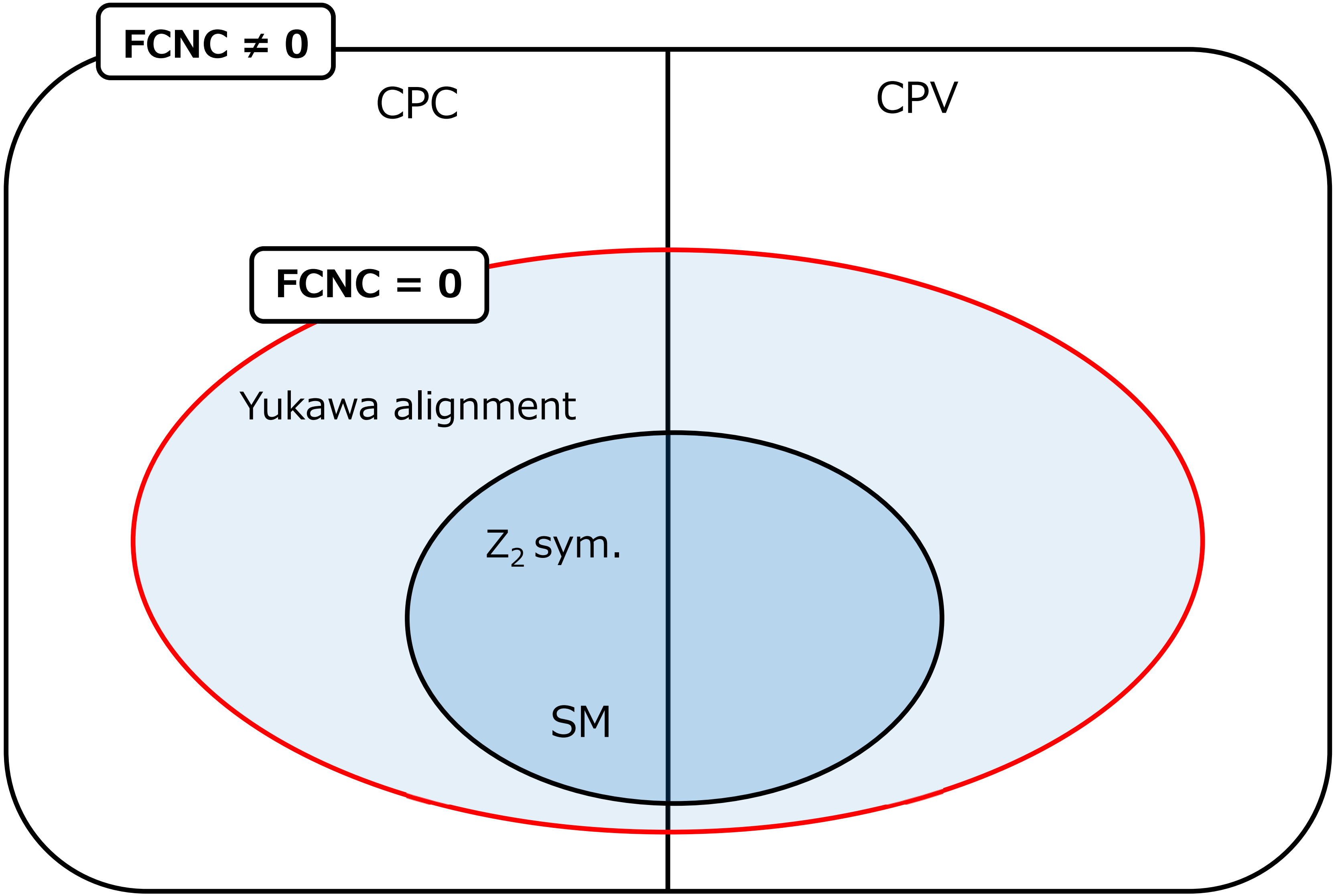
Aoki, Kanemura, Tsumura, KY (2009), Cite 300+

No FCNC

- *Pich, Tuzon (2009)*
  Yukawa alignment
  $$Y_1 \propto Y_2$$
- *Glashow, Weinberg (1977)*
  Z_2 symmetry
  $$Y_2 \to 0$$

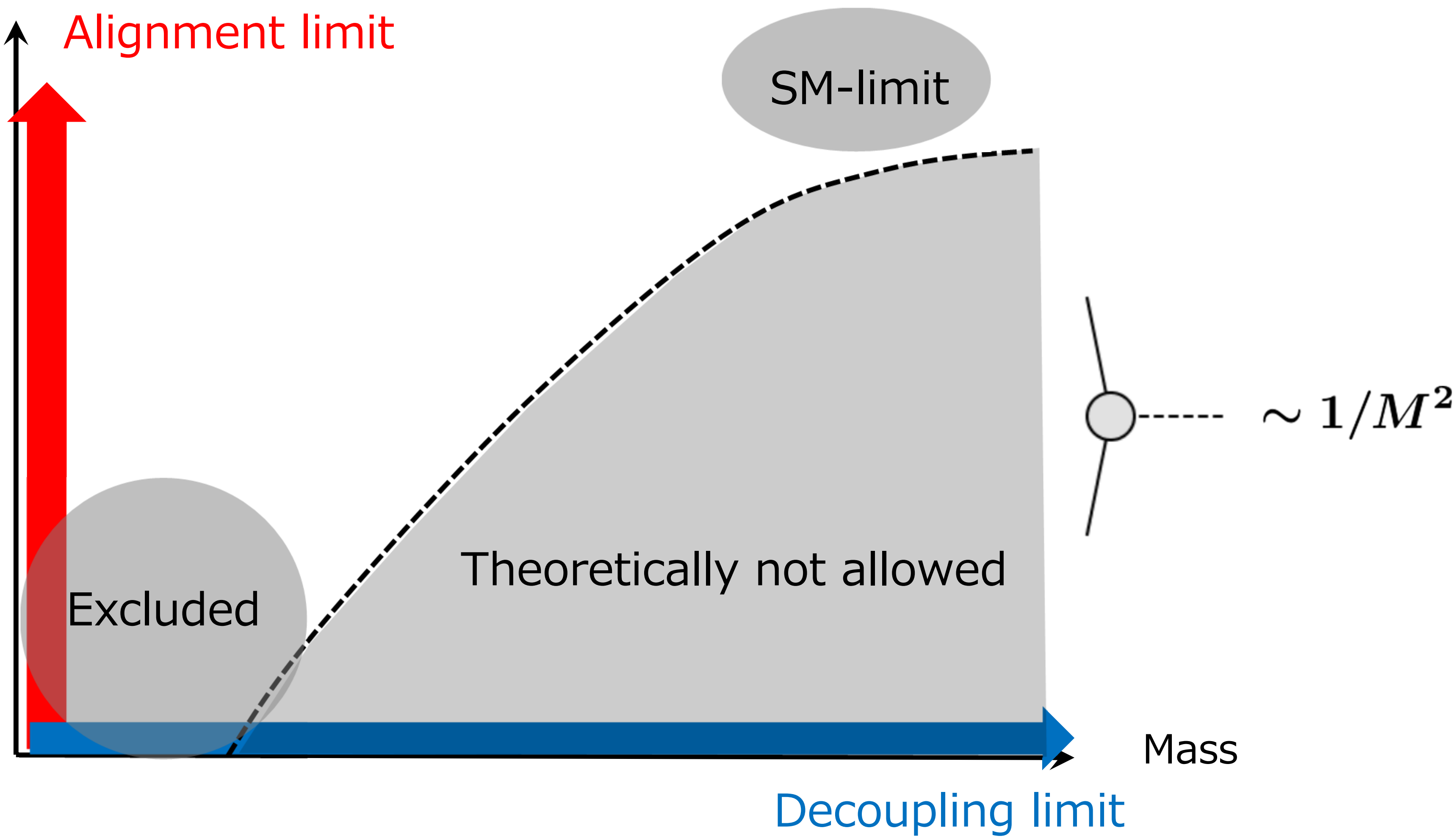


Classification of Multi-Doublet Models



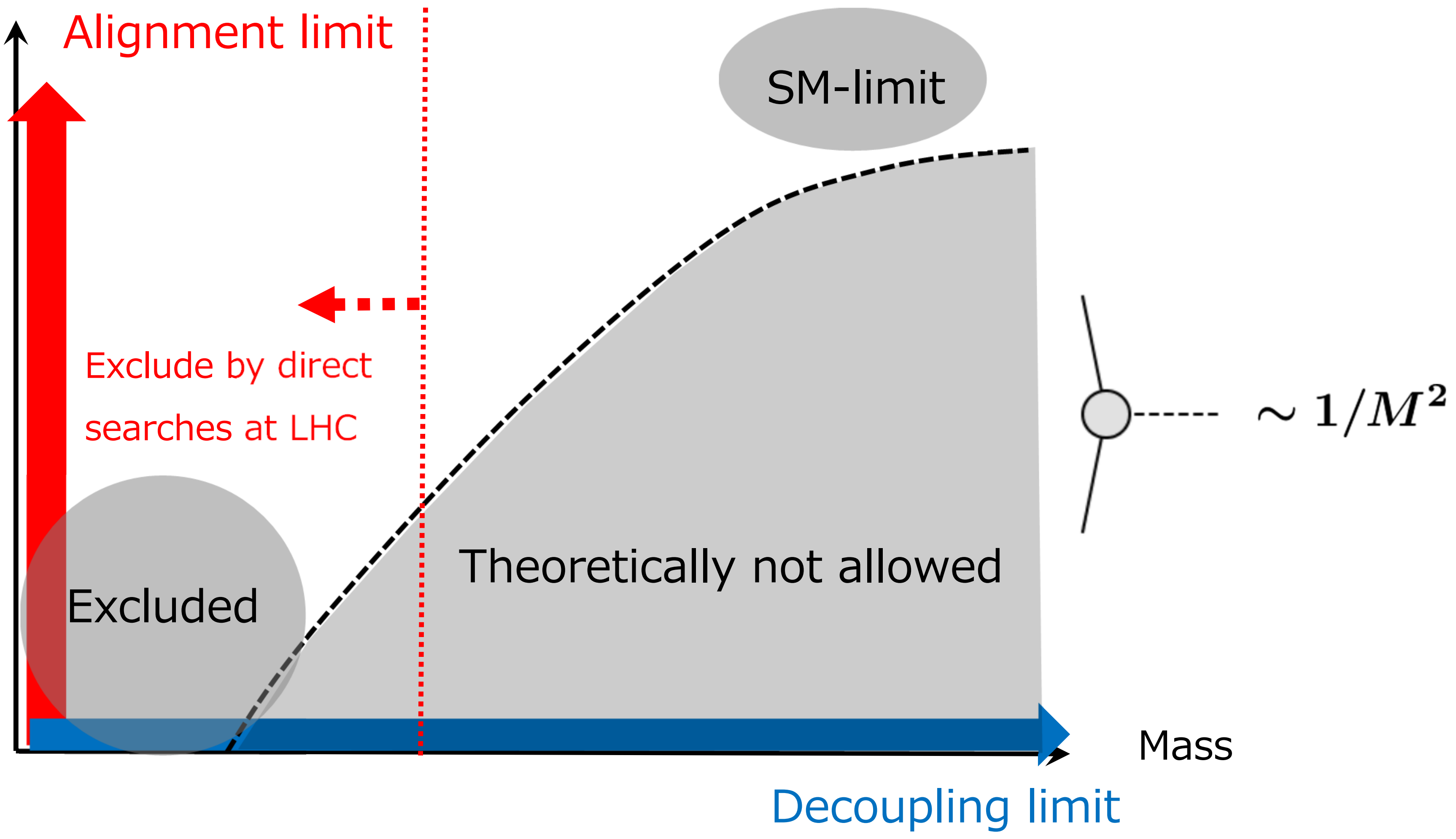
Alignment & Decoupling

SM-likeness of h(125)



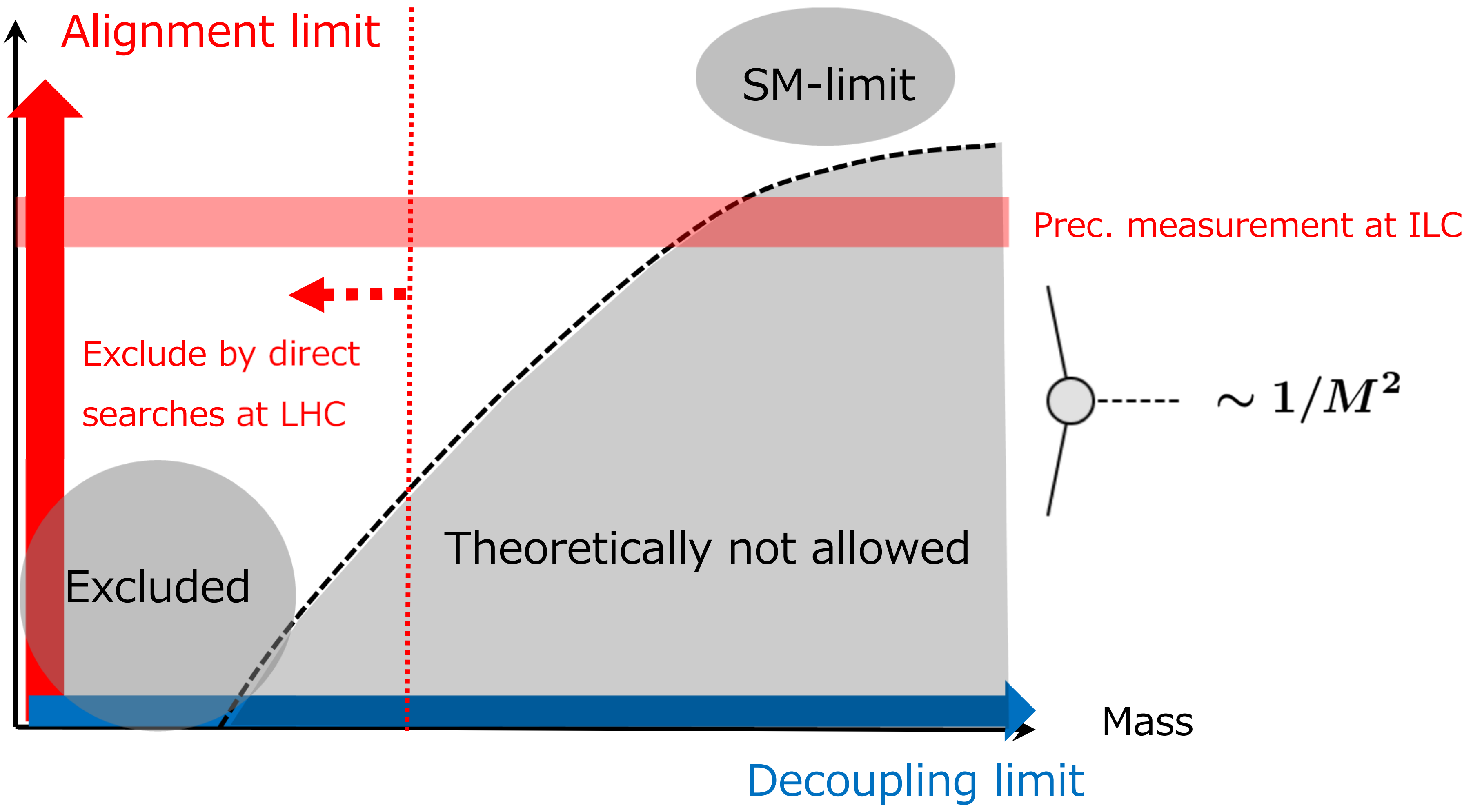
Alignment & Decoupling

SM-likeness of h(125)



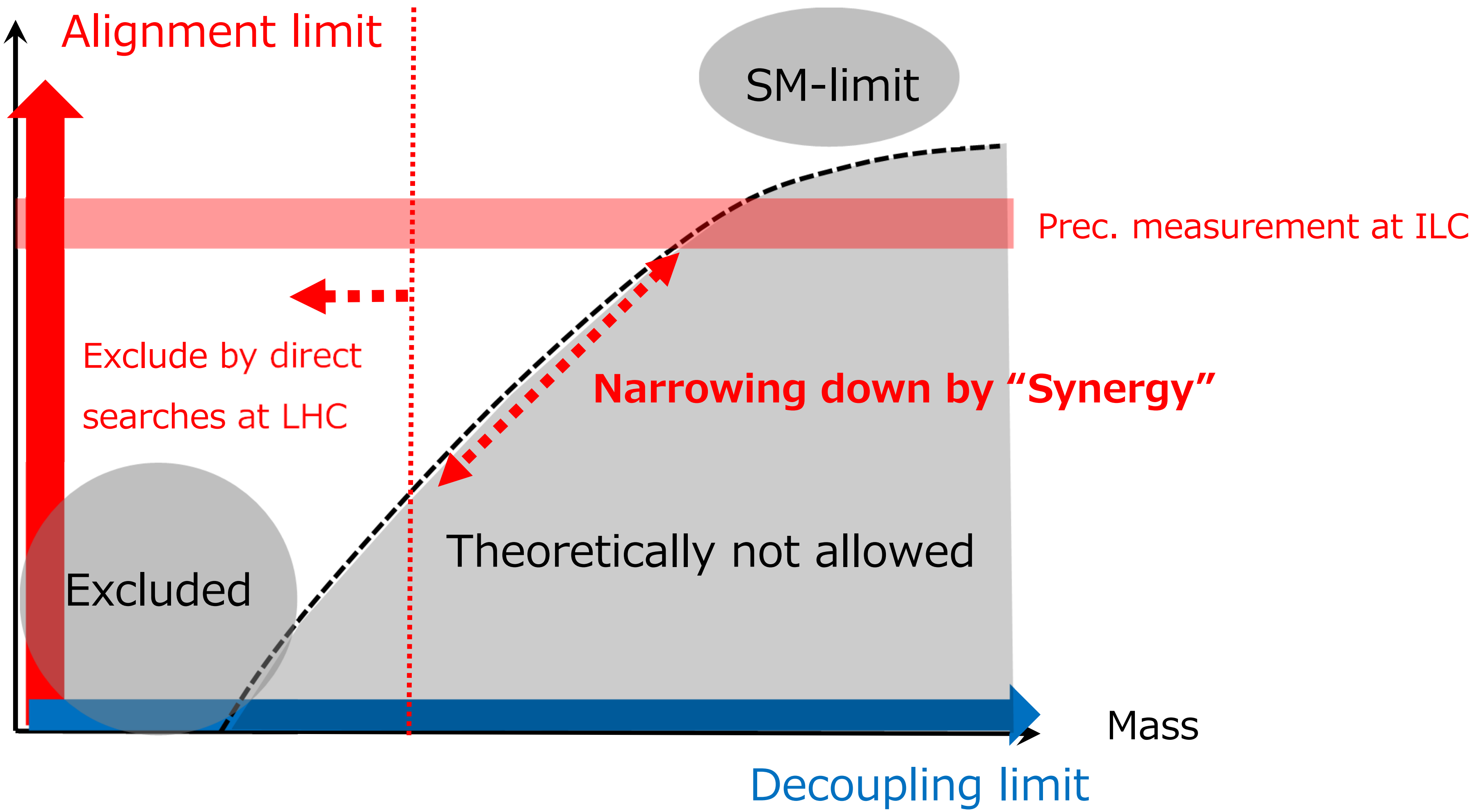
Alignment & Decoupling

SM-likeness of h(125)



Alignment & Decoupling

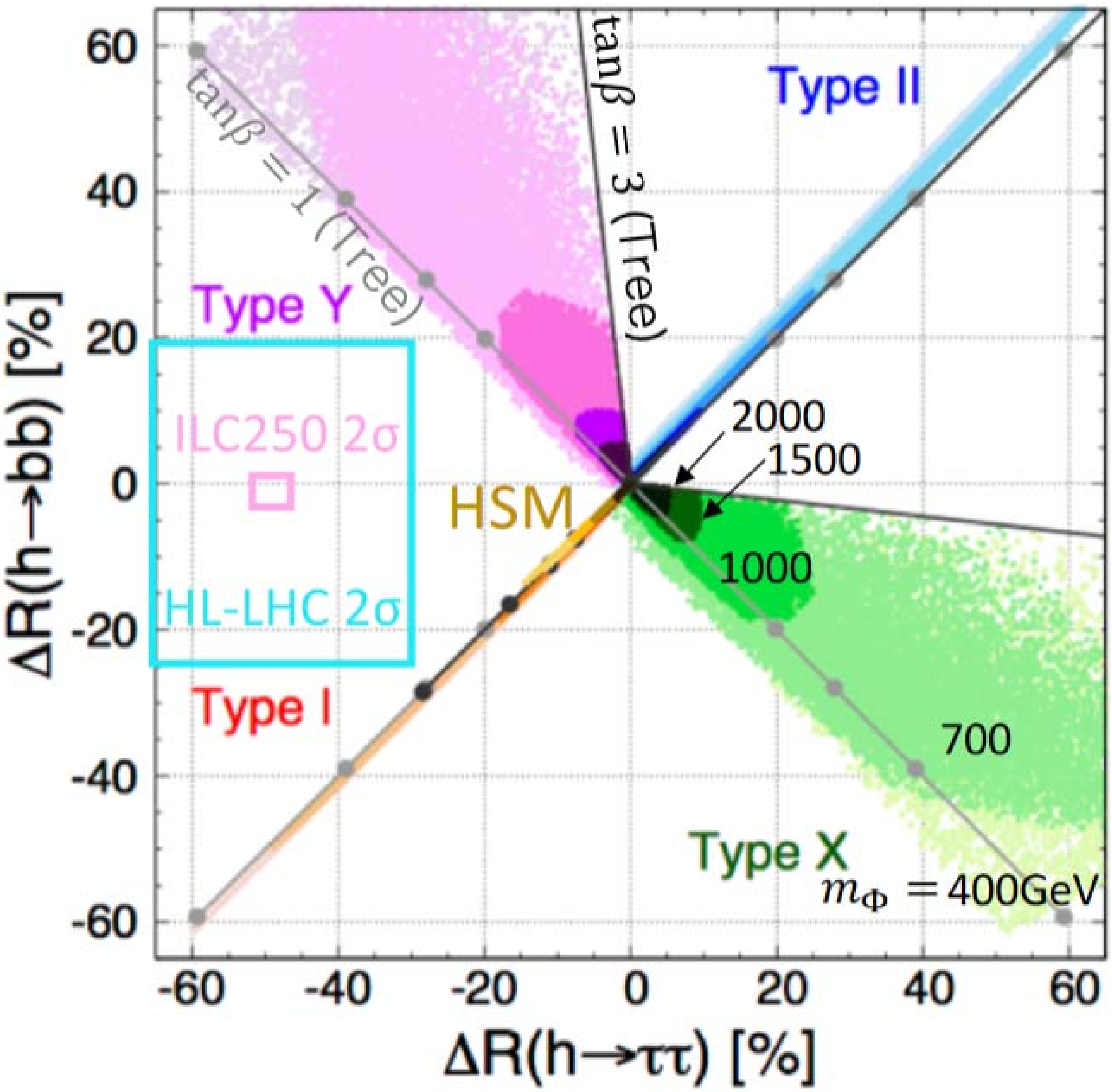
SM-likeness of h(125)

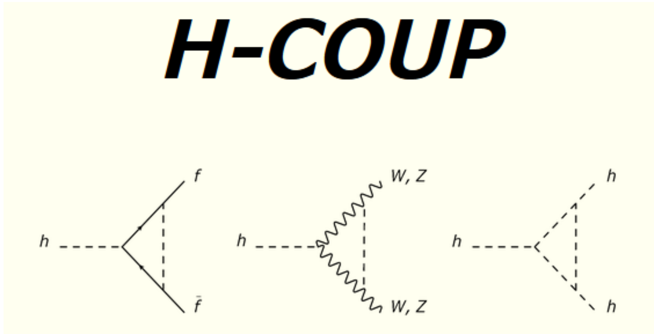


"New No Loose Theorem"

Fingerprinting

Kanemura, Kikuchi, Sakurai, Mawatari, KY, PLB783, 140 (2018)



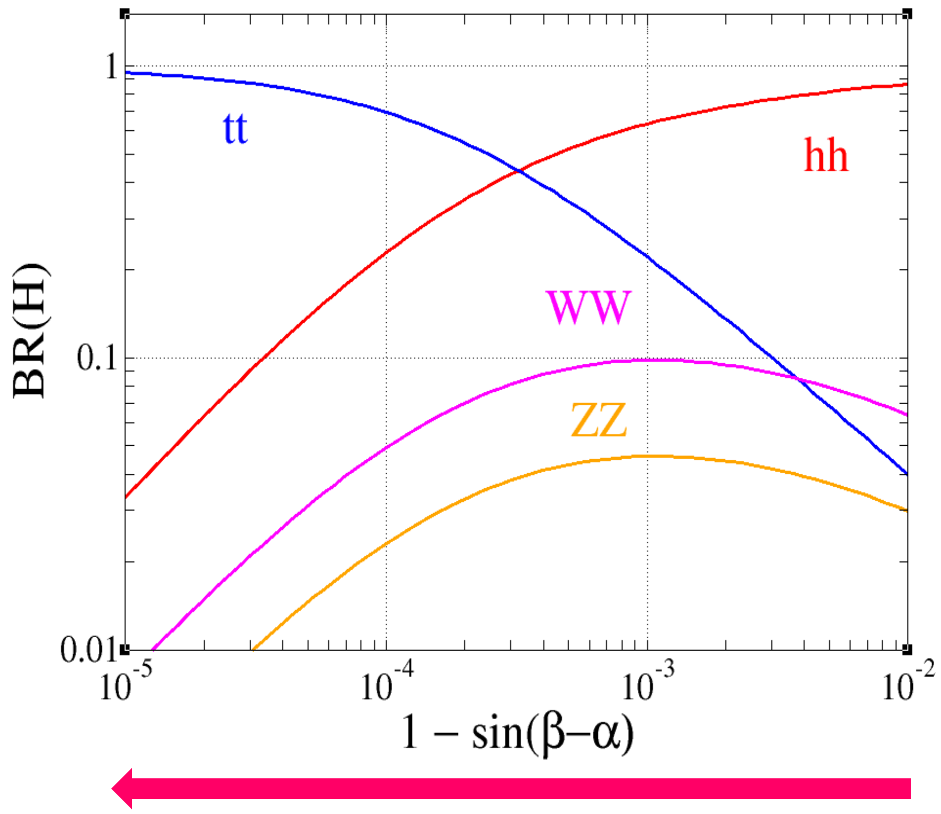


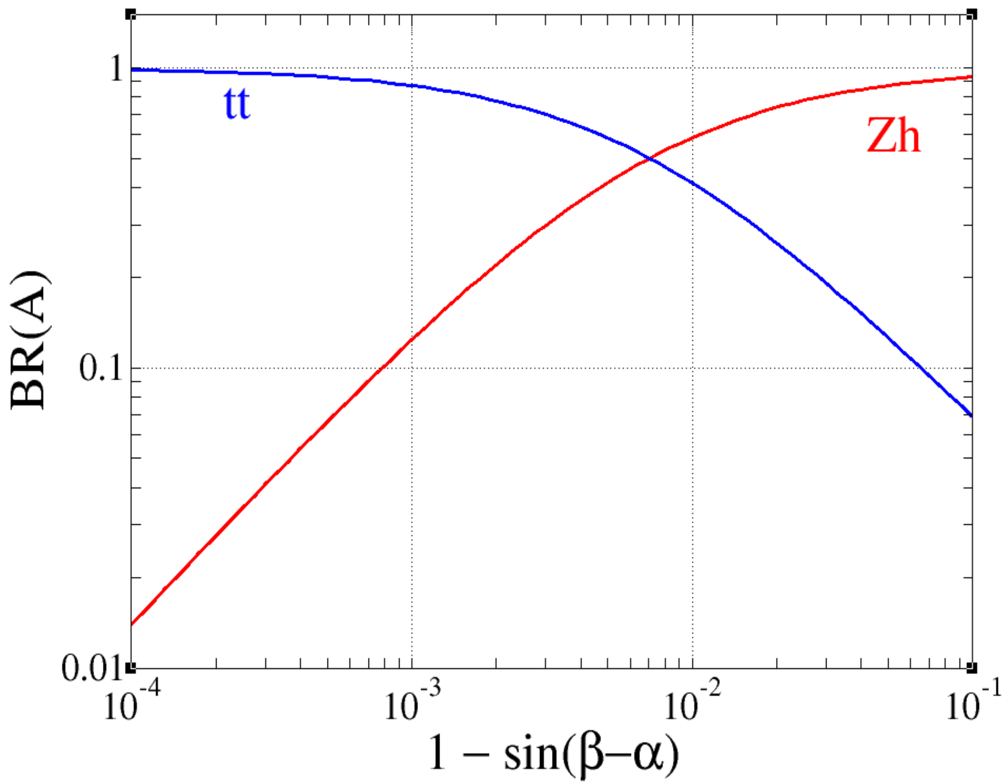
v1: Kanemura, Kikuchi, Sakurai, KY (2017)

v2: Kanemura, Kikuchi, Sakurai, Mawatari, KY (2019)

Higgs to Higgs decays @ near alignment

Type-I 2HDM with mH = mA = mH⁺ = M = 400 GeV, tanβ = 10



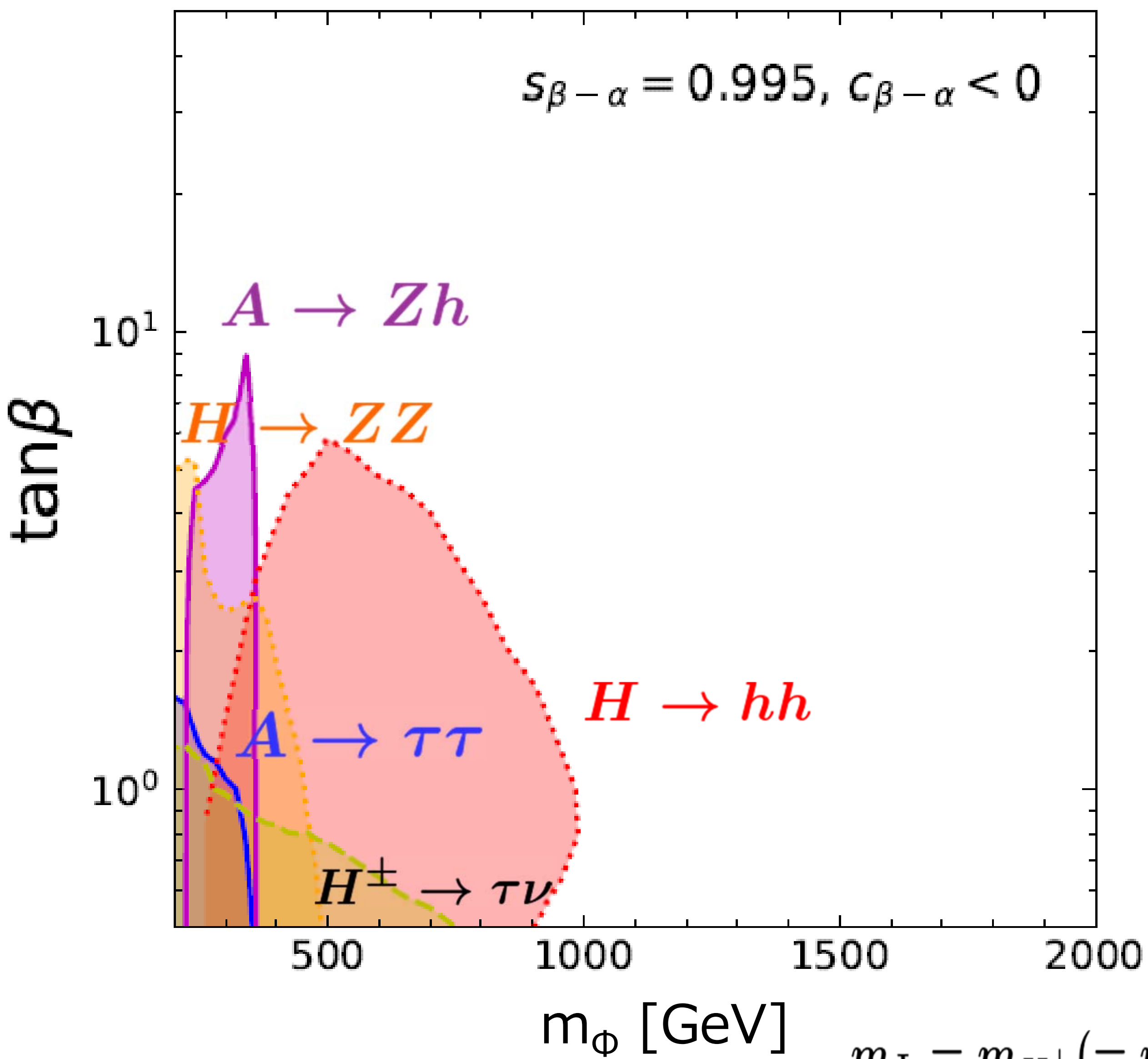


Alignment limit

Current LHC

Aiko, Kanemura, Kikuchi, Mawatari, Sakurai, KY (2020)

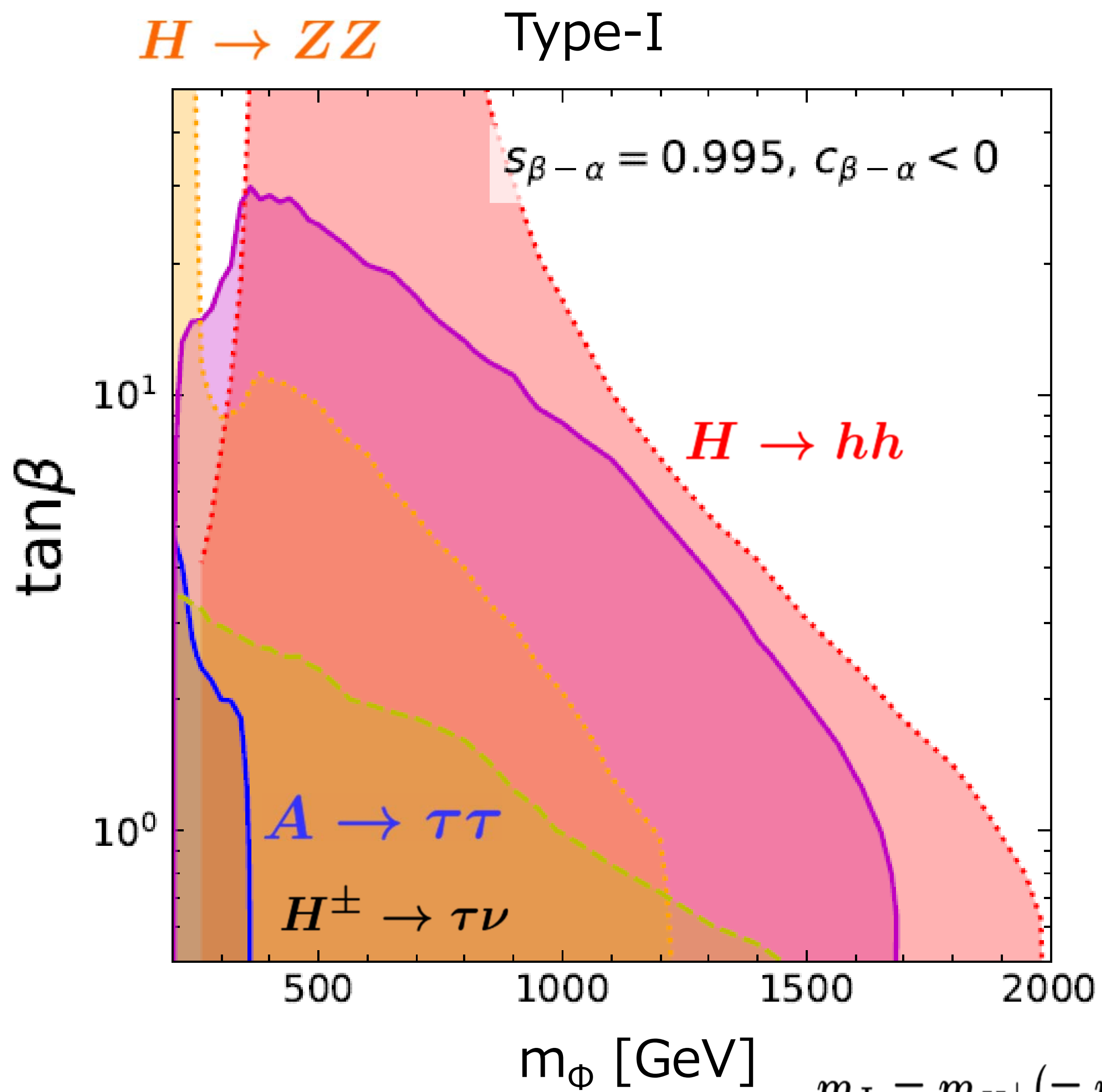
Type-I



$m_\Phi = m_{H^\pm} (= m_A = m_H)$

HL-LHC

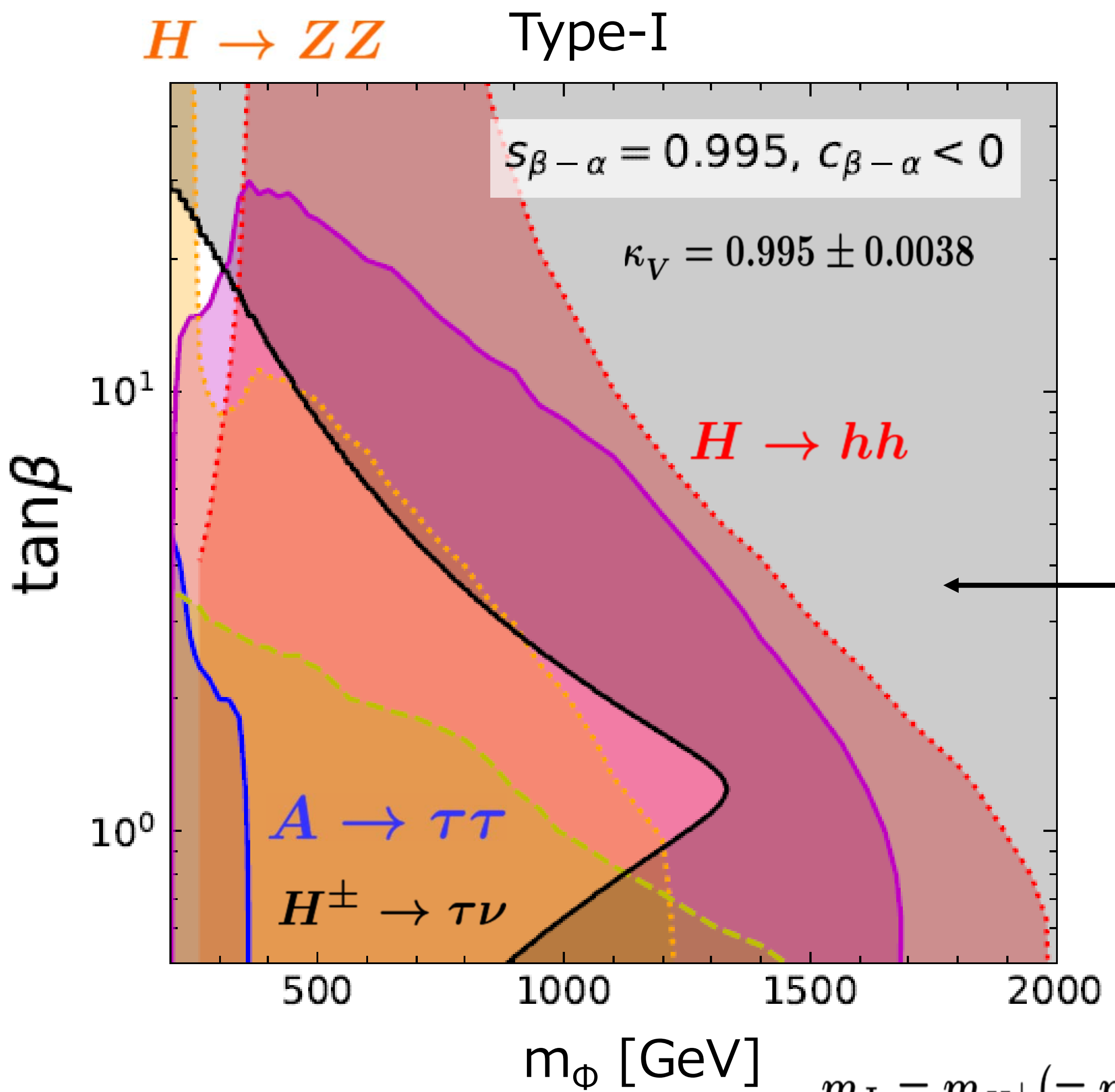
Aiko, Kanemura, Kikuchi, Mawatari, Sakurai, KY (2020)



$m_\Phi = m_{H^\pm} (= m_A = m_H)$

HL-LHC & ILC

Aiko, Kanemura, Kikuchi, Mawatari, Sakurai, KY (2020)



$m_\Phi = m_{H^\pm} (= m_A = m_H)$

Excluded by unitarity and vacuum stab.

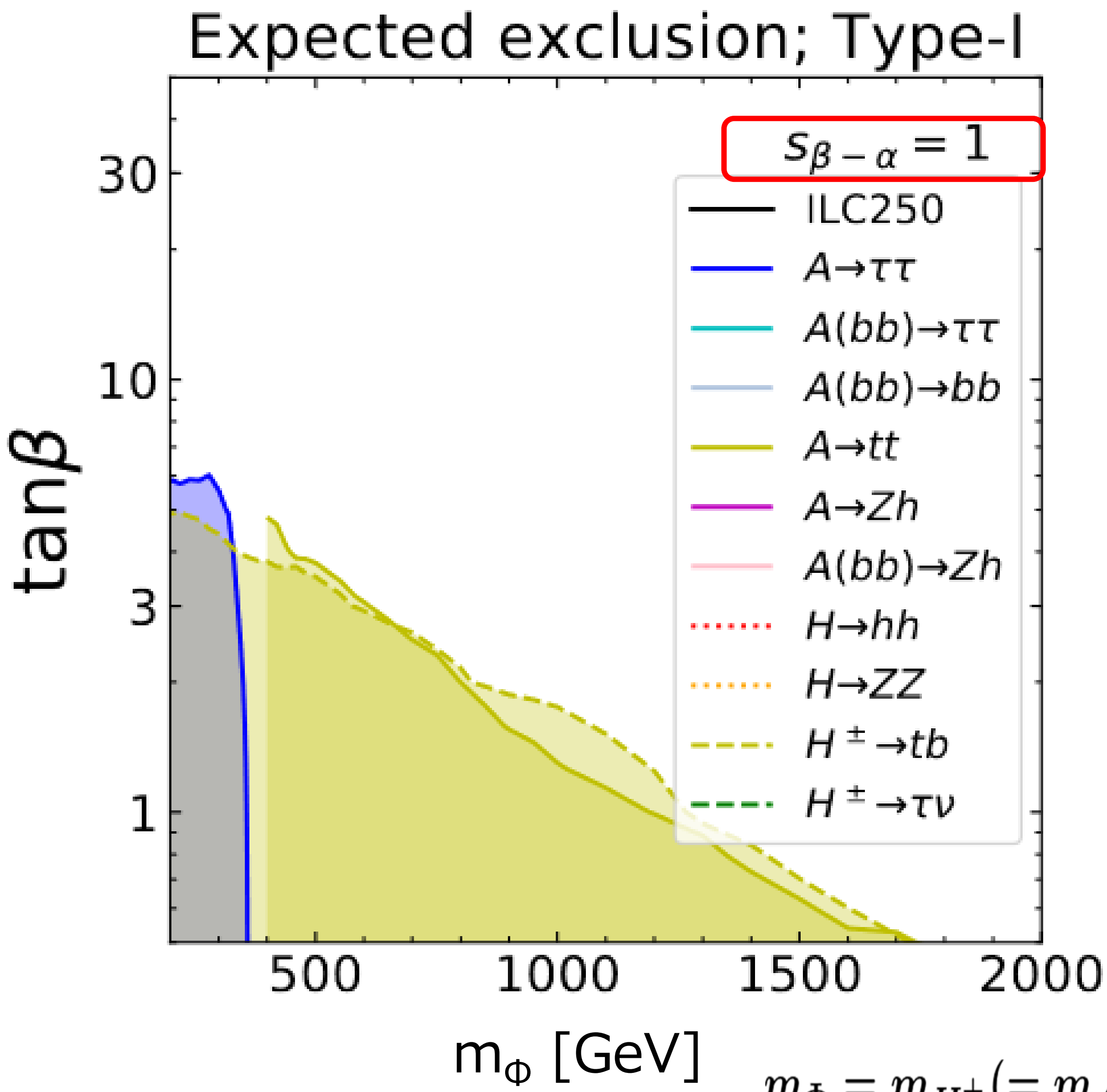
Despande, Ma (1978)

Kanemura, Kubota, Takasugi (1993)

Kanemura, KY (2015)

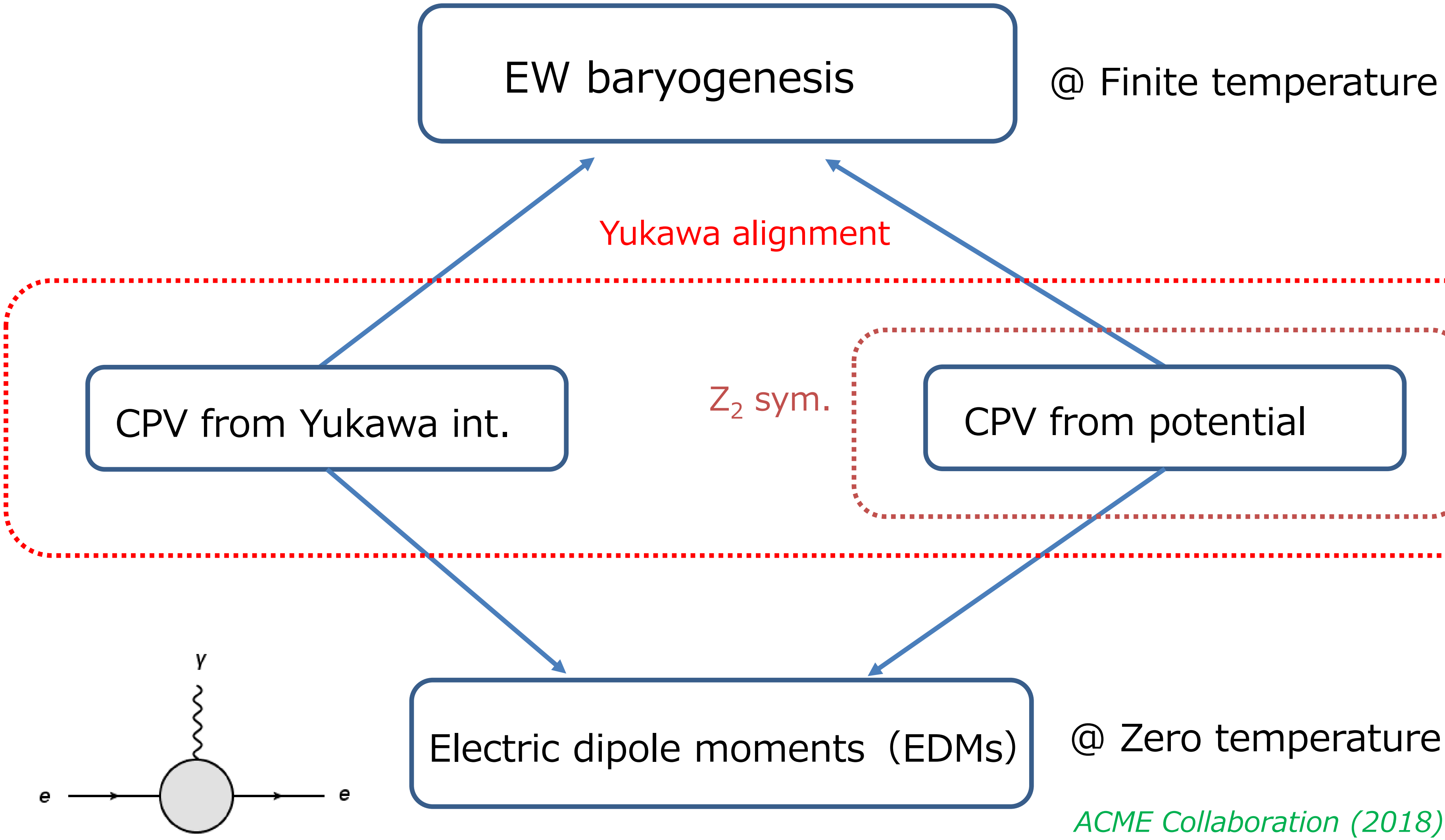
Alignment limit

Aiko, Kanemura, Kikuchi, Mawatari, Sakurai, KY (2020)



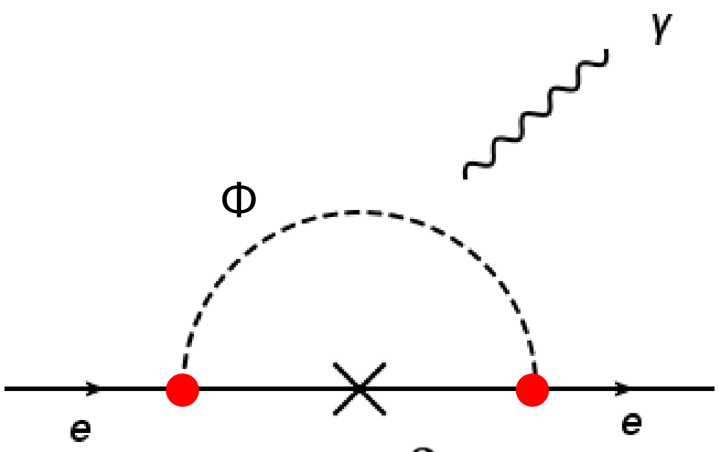
$m_\Phi = m_{H^\pm} (= m_A = m_H)$

CP-violation in the alignment scenario



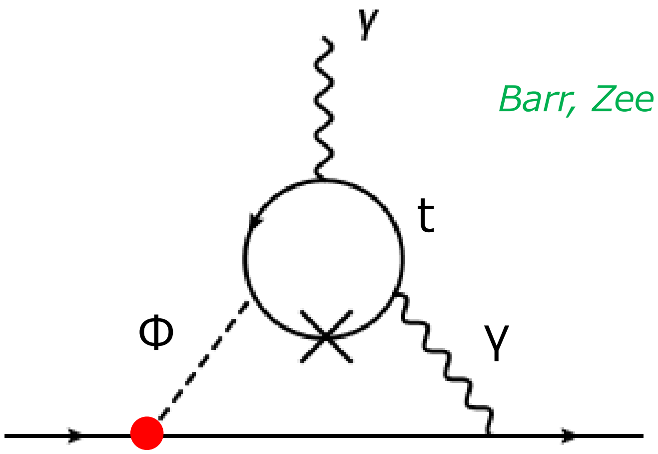
$$|d_e| \leq 1.1 \times 10^{-29}\ e\ \mathrm{cm}$$ @90% CL

Contribution to EDMs



$\propto y_e^3$

$\overset{\sim 10^7}{\ll}$



$\propto y_e$

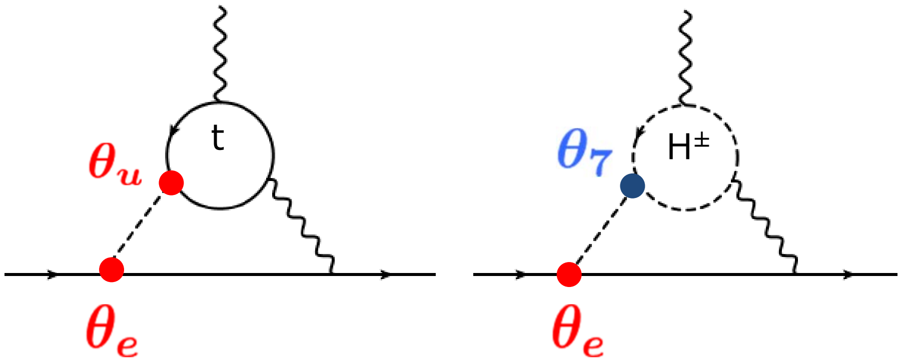
Barr, Zee (1990)

$$d_e \sim \left(\frac{1}{16\pi^2}\right)^2 \times e^3 G_F m_e \sim 10^{-27}\, e\,\mathrm{cm} \quad \gg 10^{-29}\, e\,\mathrm{cm}$$

- Typically, new source of CPV is excluded by EDM experiments.
- We need a mechanism to get O(1) without confliction to EDMs.
- Destructive interference in EDMs can happen between Yukawa & potential CPV.

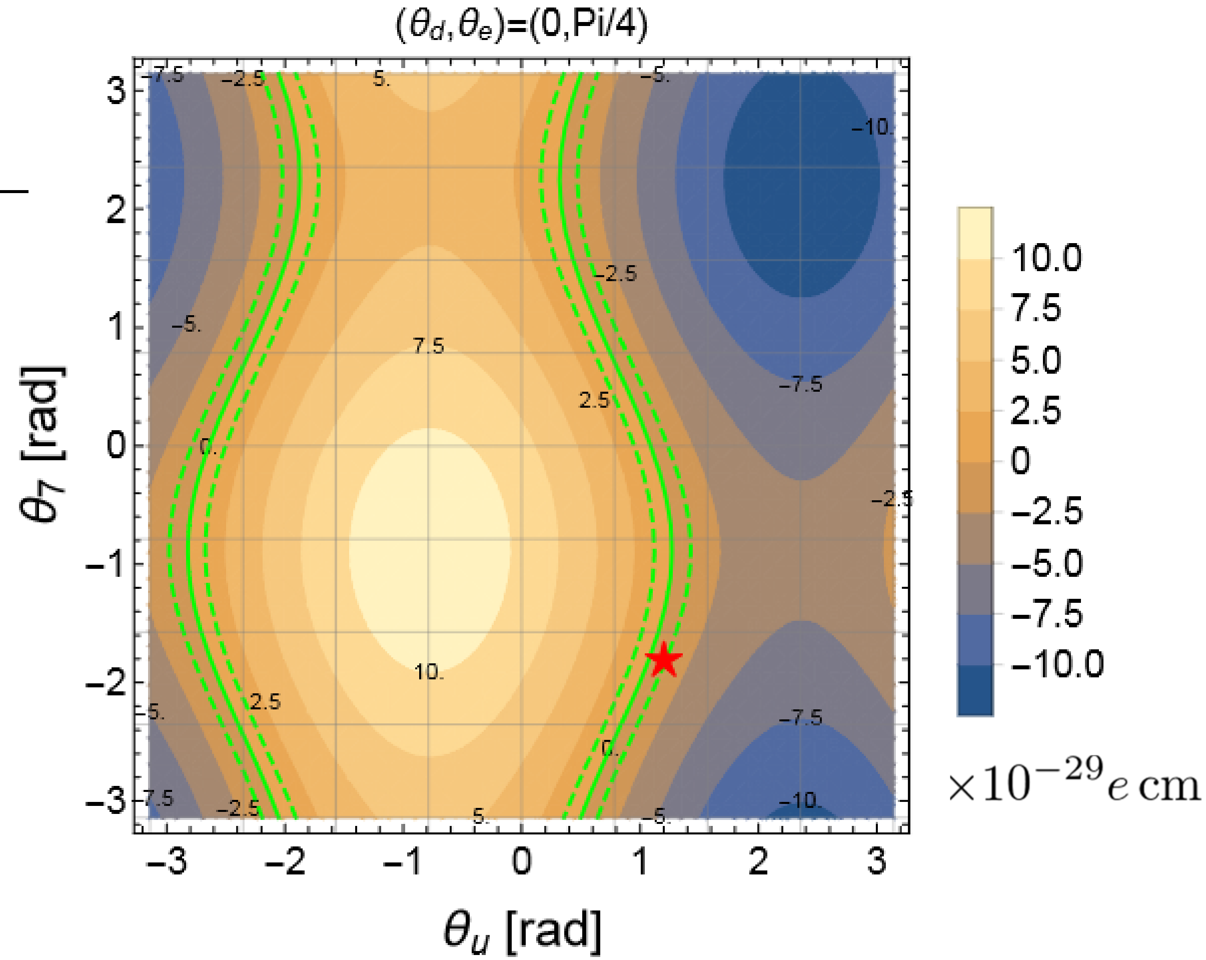
Destructive interference in EDM

Kanemura, Kubota, KY (2020)



- Benchmark point

$M = 240,$	$m_{H_2^0} = 280,$	$m_{H_3^0} = 230,$	$m_{H^\pm} = 230$	(in GeV).
$\lvert\zeta_u\rvert = 0.01,$	$\lvert\zeta_d\rvert = 0.1,$	$\lvert\zeta_e\rvert = 0.5,$	$\lvert\lambda_7\rvert = 0.3,$	$\lambda_2 = 0.5.$
$\theta_u = 1.2,$	$\theta_d = 0,$	$\theta_e = \pi/4,$	$\theta_7 = -1.8$	(in rad).

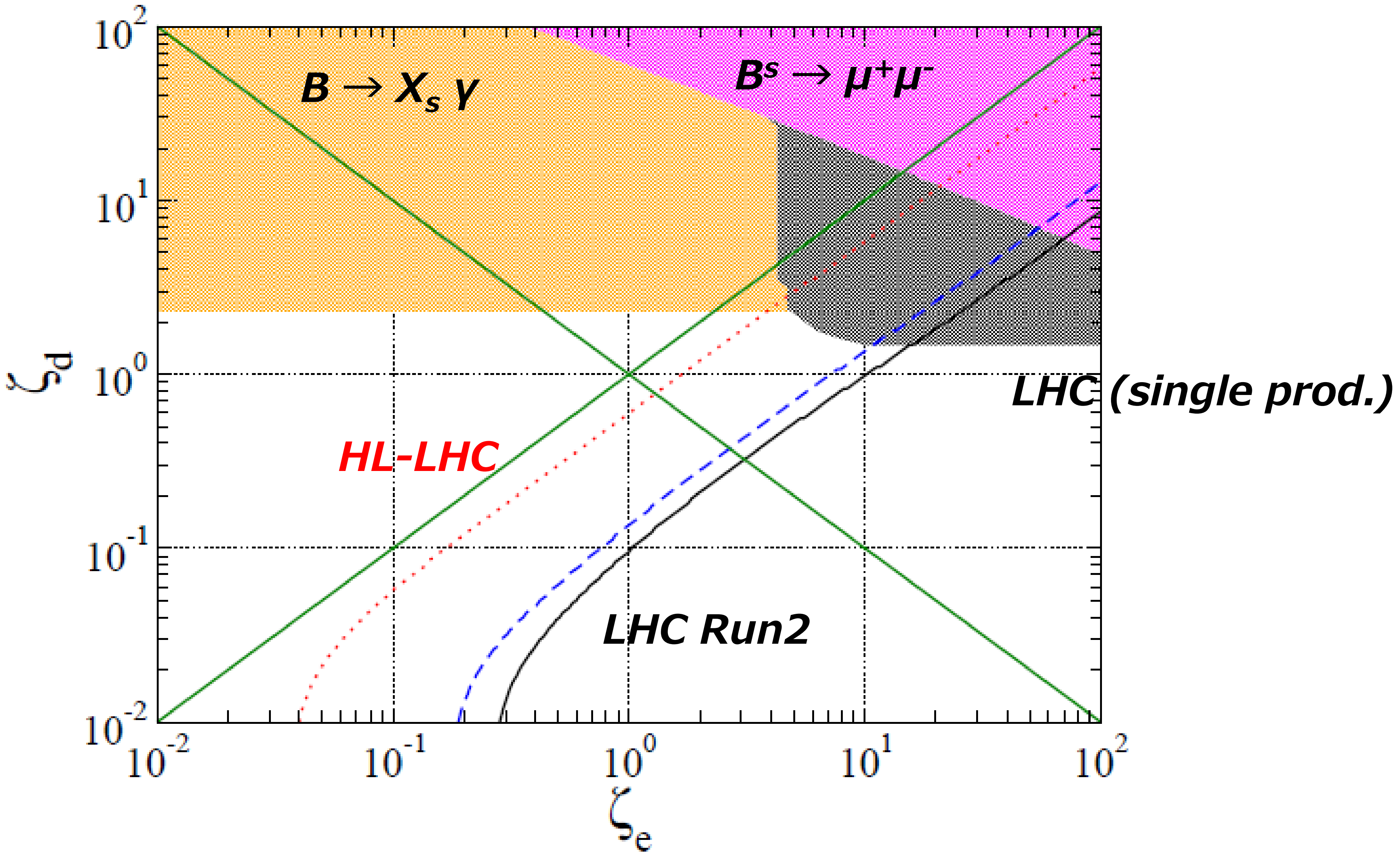


This opens a new possibility of the successful EW baryogenesis scenario.

Collider phenomenology

Kanemura, Takeuchi, KY, in preparation

m_{H2} = 230 GeV, m_{H3} = 280 GeV, m_{H^+} = 280 GeV, ζ_u = 0.1



Summary

- Higgs physics is a key to probe new physics BSM.
- The Higgs mass and top mass may indicate **criticality**.
- **EW scale** and **dark matter** can naturally be explained in the **MPP** framework.

  This can be probed by **GW observations** at DECIGO and/or BBO, and

  a light Higgs boson search at the **ILC**.
- Now, **"alignment"** is the important keyword.
- Near alignment : **Higgs to Higgs decay** & **Higgs precision** are important.
- Double alignment : **EW baryogenesis** is possible via the O(1) CPV phase.